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# A CLASS-BOOK

OF

# CHEMISTRY,

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*DESIGNED FOR THE USE OF COLLEGES AND SCHOOLS.*

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WITH OVER THREE HUNDRED ILLUSTRATIONS.

BY

EDWARD L. YOUMANS, M.D.,

AUTHOR OF

"THE CHEMICAL CHART," "CHEMICAL ATLAS," "HAND-BOOK OF HOUSEHOLD SCIENCE," ETC.

*'Man is the interpreter of Nature—Science its right interpretation.'*

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TO

*MY SISTER,*

MY COMPANION, INSPIRER, AND ASSISTANT

AMID

*PECULIAR DIFFICULTIES OF EARLY STUDY,*

AS A MARK OF

AFFECTIONATE ESTEEM

AND

EVER-DEEPENING GRATITUDE

I Dedicate this Book.

# PREFACE.

THE Class-Book of Chemistry published some ten years ago has been rewritten, reillustrated, and much enlarged, and now appears as essentially a new work. Its aim is to present the most important facts and principles of the science, in their latest aspects, and in such a manner as shall be suitable for purposes of general education.

So rapid is the progress of Chemical Science, that a book upon the subject, however faithfully it may represent the state of knowledge at the time of its publication, requires frequent and thorough revision. The past ten years have been remarkably fruitful in new facts and principles bearing upon Chemistry, the most important of which will be found embodied in the present volume.

New views of the nature and connections of the forces have been accepted in the scientific world, which compel a new treatment of this branch of the subject. The old notion, that the forces are separate and peculiar forms of imponderable matter, has given way to the idea that they are closely allied and mutually convertible forms of activity or motion in ordinary matter. The older views are held to be self-contradictory, and as they do not explain and cannot represent the present facts of science, they are abandoned by the body of advanced scientific thinkers of the present time. The newer doctrines may be still incomplete, and are not without their difficulties, but they are more simple and rational; they harmonize with the later facts of discovery, and open many new paths of investigation of the highest interest and promise.

An earnest desire to make this book a faithful reflex of the present state of Chemistry, and its connected questions, has led to the adoption of the more recent views,

and to a much fuller treatment of Chemical Physics than was contained in the earlier editions of the work. It may be proper here to remark that the author has taught these views for several years in his lectures on the 'Chemistry of the Sunbeam;' the section placed under that title in this volume touching only a single branch of the discussion.

The work will be found to embrace also other subjects of recent investigation: as Spectrum Analysis and the elements discovered by it; Prof. GRAHAM'S interesting views of Dialysis and the colloidal condition of matter; and BERTHELOT'S remarkable researches in organic synthesis, or the artificial production of organic substances, together with various other particulars of scientific progress which are not to be found in contemporary text-books.

The present work is not designed as a Manual for Chemists. To such vast proportions has the science grown that voluminous and constantly enlarging treatises are published upon each of its numerous branches. A school text-book can therefore be but a brief compend of general principles and their most important applications, and is not to be judged by the completeness of its details, or its fulness as a work of reference. In this volume descriptions of those chemical substances which are not frequently met with, as the rare metals, are omitted, and directions for making experiments have been much condensed. By this means space is gained to treat with unusual fulness the more familiar objects of nature, as oxygen, air, water, food, &c., and to introduce much new and interesting information.

Chemistry is not now what it was a few years ago—a mere matter of acids and alkalies, colored fires, and gas explosions, beginning and ending in the lecture room. It is an unfolding of the great laws of Nature, around and within us, and has an interest, not for experimenters alone, but for all who care to understand anything of the scheme of being which the Creator has established, and in the midst of which they are placed. The Class-Book is therefore designed for the wants of that large class, both in and out of school, who would like to know something of this interesting science, but cannot pursue it in a detailed and experimental way. Its copious illustrations will partially supply the lack of experiments, but lectures and demon-

strations are always invaluable whenever they can be obtained.

While the application of Chemistry to the most important arts has been duly noticed, more than usual attention has been given to the Chemistry of Nature. The order of subjects has been so presented as to unfold the order of forces in nature—what may be reverently termed the divine logic of her activities. In the First Part are considered the great natural forces by which matter is moved and transformed; in the Second Part, the application of these forces to the lower or mineral world, and the change of properties which they produce in inorganic bodies. Part Third treats of the organic kingdom, which rises out of the preceding, with the composition and changes of organic substances. In Part Fourth we see the completion of Nature's scheme in the world of life. The facts and principles of the three former divisions are here applied to the illustration of Physiological Chemistry.

In preparing the volume the author has kept constantly in view that Chemistry is not only a *branch* of education to be acquired, but that it is a *means* of education—a valuable instrument of intellectual culture. His aim has been, not only to present important information but to arouse the mind and awaken a spirit of inquiry. He has striven to carry the thoughts upward to those larger and nobler views of scientific truth which are more and more clearly revealed by the advance of inquiry, and which are fitted not only to expand the thoughts, but to awaken the best emotions of our nature.

A brief statement of the relations of science to the mind is made in the Introduction. The subject pertains to Mental Philosophy; but many will study Chemistry who have not taken up that subject, and it is thought, that to such, the suggestions offered may prove serviceable. Should teachers think it too abstract and difficult for beginners in Chemistry, it may be passed by.

In preparing this volume the author has resorted to various authentic sources of information; but the second edition of Prof. W. A. Miller's excellent 'Elements of Chemistry' has been taken as the chief guide in revising chemical data. Several passages have been transferred, with slight changes, from the 'Household Science' to Part IV.

The author would acknowledge especial indebtedness to the new 'Lectures on Heat' by Prof. TYNDALL, which contains an able and attractive exposition of the new views of heat and its connections with the other forces. He is happy in being able to state that this valuable work has been republished in this country, and he would earnestly recommend it to all teachers and students who take an interest in natural science.

He would also renew his expressions of obligation to the writings of Dr. J. W. DRAPER, of New York, a gentleman who stands alike distinguished in the field of original scientific research and of high philosophic thought.

Grateful for the kindness with which former efforts have been received, he would indulge the hope that the present may be found still more worthy the confidence of the friends of education.

NEW YORK, *June*, 1863.

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E. Hall

THE

# CLASS-BOOK OF CHEMISTRY.

## INTRODUCTION.

### ORIGIN AND NATURE OF SCIENTIFIC KNOWLEDGE.

**1.** In entering upon the study of science, it is desirable that the student should have clear ideas of the origin and nature of the kind of knowledge he proposes to acquire. There is a vague notion among many people that scientific knowledge is of a totally different nature from ordinary knowledge—that science and common sense, if not opposed to each other, are at all events very widely separated. That there *is* a difference between these two forms of knowledge is true, but it is by no means of the kind usually supposed, and it will repay a little careful attention to learn in what it really consists.

**2. Knowledge Progressive.**—To understand nature is the prerogative of the human mind, yet this work is so vast and difficult, and its results so precious to humanity, that it is given to no man or to no age fully to penetrate her mysteries. No subject—not the minutest thing—can be so exhausted that further thought and the insight of genius may not discover still deeper meanings and more subtile relations. And thus the mighty labor becomes progressive; each generation receives its inheritance of knowledge, makes its own additions, and bequeathes the whole to its successor; so that We of the present stand as

'The heirs of all the ages in the foremost files of time.'

---

1. What is stated as desirable for the student of science? What common opinion is referred to? 2. How does knowledge become progressive? 3. What is

3. Knowledge is thus a growth. It begins in the common information of the uncultivated; it develops, and in its higher forms it is called *science*. All the sciences have had their origin in the first rude actions of ordinary minds, and have grown up by slow degrees. Thus the art of counting gradually grew into the science of numbers; that of land-measuring into the science of geometry. The grouping of the stars into fantastic resemblances of animal forms by the shepherds of old was the germ of Astronomy, while the common facts of combustion, fermentation, and decay, have been slowly evolved into chemical science. But common knowledge does not change its nature in becoming science any more than does a shrub in becoming a tree, nor can the line be found where one stops and the other begins.

4. **A Test of Science.**—As the phenomena * of nature take place with perfect regularity, just to the degree in which we understand her ways we can anticipate her results. Science thus confers foresight; according to its perfection it enables us to foreknow what will take place in the future. Astronomy is the most perfect of the sciences, and hence we are enabled to predict astronomical results with absolute precision thousands of years before they occur. So also with chemistry, just to the degree in which we understand it can we foretell what will take place when certain elements are brought together. This prophetic knowledge or *prevision*, is the most rigid test of science.

5. Yet the mind of a nursery child answers to this test as well as the intellect of Newton. As has been well observed, even its acquaintance with an apple has in it the rudiment of science. It sees a certain form and color, and it knows if it puts out its hand it will have certain impressions of roundness, smoothness, resistance, and, if it bites, a certain taste. Nor can anything be more certain than the previsions of ordinary minds; for example, that unsupported bodies will fall; that water will extinguish fire, and night succeed day. Familiar as these cases are, we see in them the rudiments of

* The word *phenomena* signifies literally *appearances;* they are objects seen or events taking place in the usual course of nature, and not things rare and extraordinary, as is sometimes erroneously supposed.

science? What is the origin of all sciences? Examples? 4. What power does a knowledge of the order of nature confer? Examples? What is it called? 5. What is said of the knowledge of the child? Give examples of common previsions. What is said of them? 6. What example is given of the previsions of

the highest science; that is, a perfect accordance between the anticipated occurrences and those which actually take place.

6. **How Knowledge Grows.**—We may trace this element through all the stages of the development of knowledge. A lad knows that the smoke, from the fire he is kindling, will rise; that the fire will consume the fuel and presently warm the room and boil water. These are previsions which he makes just as certainly and accurately as the philosopher.

7. But when the mind begins to inquire, a new class of previsions is reached. It is seen that the fire will disturb the equilibrium of the air and thus cause the smoke to rise; that an element of the air will enter into chemical union with the fuel; that there will be no real destruction of matter, but only a change of its forms; that the chemical action will give rise to heat which will be propagated by conduction through the iron, by circulation through the water, and by radiation through the air. These results are not different in kind from the first—no more positive or certain; but while the facts and relations in the first case are simple and obvious to the feeblest apprehension, in the latter they are more complex and obscure, and to grasp them requires a higher exercise of reason.

8. But the evolution proceeds still higher; at first there is only certainty; at last there is exactness. First the *kinds* of effect are foretold, and then their *amount*. The weight and pressure of the air, the rate of its expansion by heat, the amount of its ascensional force, and how much the chimney retards by friction, are precisely determined; and the consequent power of draft is predicted. Not only that oxygen combines with the fuel, but exactly how much will be required to consume it, what quantity of heat will be generated, how much water boiled, and space warmed, are finally foretold. In its completest form Science advances to *measurement:* it first determines qualities, then quantities.*

9. Thus is common knowledge constantly rising into the higher and more perfect form of science; its tendency is ever from the im-

* For an able exposition of the doctrine here glanced at, see HERBERT SPENCER'S *Illustrations of Progress*, art. 'Genesis of Science.'

ordinary knowledge? 7. What higher previsions may arise from these? What is the difference between them? 8. What others are mentioned in the third stage of evolution? Give illustrations. 9. What is said of the mental operations which

mediate to the remote, from the loose and vague to the definite and exact. If now we examine those mental operations by which knowledge is developed we shall find them to be one and the same in all the degrees of its evolution. Mind acts according to its necessary laws, which are identical in the child, the adult, and the most advanced philosopher.

**10. Observation.**—By the impressions produced upon the senses our attention is constantly solicited to the objects around us, and the giving of this attention is called *observation*. This is the basis of experience and the first condition of all ordinary knowledge. The person who carefully remarks the conduct and appearance of people, giving attention to their peculiarities and differences, is called an 'observer of human nature.' And so the agriculturist who notes whatever pertains to soils, stock, fruits, &c., is known as an 'observing farmer.'

**11.** Science also begins exactly here; its basis is observation. But the hasty and careless observations of people in the ordinary affairs of life, where appearances are constantly misinterpreted and everything is seen in the light of preconceived ideas, would be a very insufficient foundation for science. Its first step, therefore, is to educate this faculty by a systematic discipline. Observation is not mere looking or listening; it is *discrimination*. It is the eye of reason that observes. For purposes of science observations must be made with patience and caution; numerous sources of error from without and within—sources of which people generally are entirely unconscious—have to be vigilantly guarded against, or the results are worthless.

**12. Experiment.**—Here again we commence with the ordinary experience of mankind; everybody makes experiments. We wet, heat, scratch, bend, press, and tear substances to test their qualities. We try the fastness of colors by washing a fabric, and the genuineness of coin by its sonorous ring. But what is thus begun and practised in a rude way by everybody, science improves and carries out in a systematic manner. Its cultivators not only passively observe, but, with hand and instrument, in a thousand ways they put nature to direct trial. Objects are placed in as many different conditions as the operator's ingenuity can contrive,

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produce science? 10. What is observation? Mention common instances. 11. What is the basis of science? How does scientific differ from common observation? 12. What examples are given of common experimenting? How does

and the changes noted and compared. Only by this assiduous cross-questioning of nature by thousands of investigators has our knowledge of her laws been enlarged in extent and increased in exactness until it has reached its present advancement.

**13. Diversity of Natural Objects.**—The objects and operations of nature with which observation acquaints us are innumerable. Each region of the earth produces its peculiar forms of life; each tree has its own appearance; each leaf its peculiarity; each animal its distinguishing marks; each stone its individual features. No two faces, no two blades of grass, and, as the microscope shows, no two grains of sand are precisely alike. So also with the occurrences of experience. No season is like its predecessor; no day repeats another; no event is ever exactly reproduced.

**14. Abstraction, Generalization, Classification.**—This vast multiplicity of objects and events would confuse and confound the mind if it attempted to grasp or remember them all. The facts must be grouped or bound together in bundles before the mind can command them for purposes of general knowledge. Observation accumulates individual facts; the mind then searches for some point or quality in which a great number of objects *agree*, and having found it, gives them a common name. Thus all animals having a spinal column were grouped together as *vertebrates;* all trees which grow by the successive addition of external layers as *exogens.*

**15.** As this act of the mind puts aside those particulars in which objects differ, and separates or abstracts those of resemblance, it is called a process of *abstraction:* as it is a passing from particulars to generals, it is called *generalization;* while this sorting of a multitude of things into parcels for the sake of knowing them better and remembering them more easily, is called *classification.*

**16.** But this is no peculiarity of science, for all minds inevitably proceed in the same manner. Were a basket of fruit placed before a child, it would very naturally separate and group together the apples, the pears, and the plums; it would therefore perform the operations of *abstraction*, *generalization*, and *classification.*

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science improve upon this? What is the result? 13. What is said of the diversity of natural objects? 14. What would be the effect of trying to remember them all? What has to be done? Examples. 15. What is abstraction? Generalization? Classification? 16. What familiar examples are offered? 17. Describe the illus-

Were the chemical elements placed before it on a table, it would also naturally separate all the shining metals from the rest, and thus take the first great step in chemical classification. Those mental operations which are practised by everybody in an unconscious and imperfect way, give rise at length, by culture and discipline, to comprehensive scientific methods.

**17. Induction.**—This term denotes an essential operation of the mind, by which knowledge is acquired, and which is just as well exemplified in every-day experience as in the highest efforts of thought. For example, you place a piece of oak wood in the fire, and it burns; you then put pieces of maple, pine, and mahogany in the fire, and they also burn. From these facts you gather the general principle that all wood will burn. This is called an induction, from *induco*, *to lead in*, and signifies the bringing in of one fact after another to establish a general truth. It is true there are thousands of varieties of wood, and you have tried but three or four; yet from your *experience of nature* you conclude that what is true in certain cases will be true in all similar cases. If you observe in a larger number of instances that wood burns, the induction is strengthened.

**18. Deduction.**—If now you meet with a new variety of wood, you immediately think in the following manner, which is called a syllogism: All wood is combustible; this substance is wood, and therefore it will burn. In this case you take the induction as a general principle, and apply it in a particular case. This is deduction, from *deduco*, *to lead down*, and signifies the descent from a universal truth to a special application. Thus induction *discovers* principles, while deduction *applies* them.

**19. Verification** is testing the truth of a conclusion. Should you hear various persons from different parts of the world assert that they have tried many kinds of wood and find that they all burn, you would say this is an *experimental verification* of the law. Or if a chemist should say, I have analyzed many kinds of wood, and find that they all consist of the same combustible elements; other chemists obtain the same results with other sorts, and as the mode of vegetable growth and the essential constituents of plants are everywhere the same, all wood *must* be combustible, you

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tration of induction. What does the word signify? What is its basis? 18. If a new kind of wood is met with, how does the mind proceed? What is deduction? 19. What is verification? Describe the experimental and theoretical verifications.

would look upon this as a *theoretical verification* of your law. You would further say, this principle is true, because it may be *verified* by anybody at any time.

**20.** The grandest discoveries in science are made in precisely the same way. The master minds of our race, by a course of toilsome research through thousands of years, gradually established the principles of mechanical force and motion. Facts were raised into generalities, and these into still higher generalizations, until at length the genius of NEWTON seized the great principle of attraction, which controls all bodies on the earth and in the heavens. He explained the mechanism and motions of the universe by the grandest induction of the human mind.

**21.** The mighty principle thus established now became the first step of the deductive method. LEVERRIER, in the solitude of his study, reasoning downward from the universal law through planetary perturbation, proclaimed the existence, place, and dimensions of a new and hitherto unknown planet in our solar system. He then called upon the astronomer to *verify* his deduction by the telescope. The observation was immediately made, the planet was discovered, and the immortal prediction of science was literally fulfilled.

**22. Hypothesis.**—This is a supposition or guess put forth to account for any occurrence or state of facts. For example, a boy misses his knife. Various conjectures go rapidly through his mind as to the cause of its disappearance. He may have mislaid it, left it in another pocket, or it may be lost, lent, or stolen. Each of these ideas involves a *hypothesis* of the loss of the knife. These he proceeds to test one after another; he examines his pockets, searches in various places, inquires of his companions, but cannot find it; that is, each of his hypotheses fails when he attempts to verify it. At length, perhaps, it is found upon a comrade under circumstances which establish the hypothesis of its theft. Thus hypotheses, instead of being the mere fine-spun fancies of unpractical thinkers, as is too commonly supposed, are employed every day by everybody as the only guides of conduct and action. Literally a hypothesis signifies a supposition *placed under* the facts as a platform to support them.

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20. What example is given of scientific induction? 21. How was it applied deductively? How verified? 22. What is a hypothesis? Describe a familiar use of hypothesis. Of what essential use are hypotheses? 23. What is the literal

**23.** All scientific inquiry begins in the same manner with guesses. The facts being observed, various conjectures or hypotheses are made to explain them. It cannot be denied that in science, as in common life, there are various aptitudes for making hypotheses which no precepts can teach. It depends largely upon boldness of thought and fertility of invention; upon an original cast of the intellect—the questioning temper—the busy, suggestive mind—the piercing glance of genius, which sees what others overlook, which prizes what others neglect, which takes its flight beyond rules, and is a law to itself.

**24. Insufficiency of Hypothesis.**—But it is not by skilful conjecture that knowledge grows, or it would have ripened thousands of years ago. It was not till men had learned to submit their cherished speculations to the merciless and consuming ordeal of verification that the great truths of nature began to be revealed. KEPLER tells us that he made and rejected nineteen hypotheses of the motion of Mars before he established the true doctrine that it moves in an ellipse; and Dr. FARADAY remarks: 'The world little knows how many of the thoughts and theories which have passed through the mind of a scientific investigator have been crushed in silence and secrecy by his own adverse criticism.'

**25. Theory** means literally a *view*. It is an accepted hypothesis; an explanation of phenomena. For example, the principles which explain the structure and movements of a watch form the theory of the watch. It is common to contrast theory with practice, disparaging the former and commending the latter; but this is erroneous. Theory is derived *from* practice; indeed, it is a knowledge of the principles by which practice accomplishes its end.

**26. Cause and Law.**—Any agency which produces an effect, and which when known explains it, is termed its *cause;* while the manner in which the force acts in producing the effect is termed its *law*. Thus the cause of the fall of a stone is the force of gravitation, while the conditions under which the power acts is called its law; viz., that bodies attract each other with a force directly proportional to their respective masses and inversely as the square

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meaning of *hypothesis*? Where does scientific inquiry begin? Upon what does skill in making hypotheses depend? 24. What beside hypothesis is necessary to denote science? What is said of KEPLER? What does FARADAY observe? 25. What is a theory? How is it related to practice? 26. What is a cause? What

of their distances. The *cause* of chemical combination is the force of affinity; the *law* of the force is that bodies combine in definite and constant proportions. Strictly speaking, that which invariably precedes an act, its antecedent or several antecedents, constitutes its cause; while such an expression of the condition in which the power acts, or the event occurs, as enables the result to be determined beforehand, is known as the law.

**27.** We may call the first conjecture of universal attraction in the mind of NEWTON, which he believed probable, but held in suspense for many years, an hypothesis. But when important facts which apparently contradicted the hypothesis were revised and found to agree with it, it assumed the character of a *theory*, and as such it was on trial for a hundred years, until the greatest mathematicians, clearing away difficulty after difficulty, demonstrated it to be a universal *law*.

**28. Empiricism** ordinarily signifies mere pretension and quackery, but in science it denotes the results of observation just as they are obtained, before they are reasoned upon or reduced to principles. Empirical results of inquiry are the naked facts without any theorizing or attempts to explain them (150).

**29. Science and Art.**—As science represents the later stage of knowledge, art represents the earlier. Men first, through painful toil, servile imitation, and blind rules, learned *what* to do; then came the question *why* it was done, and the advance was made to theories and explanations, or *science*. Art is therefore empirical, science rational; art asks for rules, science for reasons; art is an affair of practice, science of principles and causes. The first is the root, the latter the outgrowth. The arts and sciences mutually help each other forward. Art presents to science her difficulties; science solves them, and, while thus increasing her own stores of truth, returns to art principles for her better guidance.

**30. Why Science is so Recent.**—For thousands of years the race lingered in the early or art-period of knowledge. This was not for lack of intellectual activity, but from its misapplication. The ancient philosophers, disdaining nature, retired into the ideal world of pure meditation, and holding that the mind is the meas-

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a law? Examples? 27. What example is there of the growth of a hypothesis to a theory and how? 28. What is empiricism? 29. What are the relations of art and science? What did men first learn? How are science and art constructed? How do they help each other? 30. What was the state of mind of the ancient

ure of the universe, they believed they could reason out all truths from the depths of the soul. Despising matter, they were not drawn to observe and study it: despising labor as menial and degrading, they would not experiment; consequently they lacked the first conditions of science, Observation, Experiment, and Induction. They reasoned from fanciful notions to worthless conclusions, and the intellectual power of ages was thus wasted. Genius spent itself in beating the air; the philosophers wrestled with shadows; they chased each other round the circles of verbal disputation, they pursued the rainbow, disdaining the priceless gems which abound in the earth beneath. It was the period of inexperience, and their mistake was perhaps natural, but it was an error that paralyzed the world. The first step of progress was impossible. There was no conquest of nature or liberation of man from the drudgeries of endless toil; no spirit of general inquiry, no projects of education or hope of improvement.

31. **Succession of the Sciences.**—Thus the sciences do not rise or advance together; they have appeared in succession—the earlier, as it were, preparing for the later, and the later springing out of the earlier. Man was first impressed by the beautiful regularity of the celestial motions; they excited his wonder and aroused his thought; and hence *Astronomy* is the oldest of the sciences. Then the visible movements of earthly bodies were also found to be governed by invariable laws, and *Mechanical* science was the result. The human mind having now established the idea of order in the heavens and on the earth, it was next found that the deeper changes which go on *within* material objects, altering their nature and properties, are also of an invariable character; and then appeared the science of *Chemistry;* and when, still later, the same thing was perceived in living beings, there arose the science of *Physiology.*

32. Many subjects are now in the rudimental condition of common knowledge which are yet to assume the scientific form, while some are capable of only a partial development. Science furnishes the only true method of their study, while yet they are so complex that the human mind may never be able completely to analyze them For example, Commerce, Education, Society, and

philosophers? Why did they fail in science? What was the consequence of their attitude of mind? 31. In what manner have the sciences appeared? In what order? 32. In what condition are many subjects at present? What is said of

History are not properly to be considered as sciences; yet the operations of business, the culture and growth of mind, the social relations of men, and the course of the world's events, inasmuch as they all unquestionably involve fixed principles and the action of uniform causes, must become more and more scientific in the method of their treatment.

33. **Claims of Science.**—The idea thus briefly illustrated, that knowledge is by its very nature progressive—that it grows into the higher form of science through the education of the essential faculties of the common mind—is of the deepest significance in education. We see that science is not a mere curious and profitless prying into the obscure recesses of nature, nor a rigid system of thought inapplicable and worthless in the walks of common experience. On the contrary, it is a result of the mind's normal growth—a product and proof of its completest discipline. By a gradual transition we rise from the obvious and simple to the remote and complex; the same faculties being called into progressively higher and more systematic exercise in the ascending course of scientific inquiry.

34. We observe, also, that science is not, as is often said, simply an affair of the material world, nor its progress a mere physical progress. All science is of the mind, and its progress mental, and whether thought be directed without, to material things, or turned within to study itself, the same intellectual operations are employed. The progress of Chemistry, the advancement of Agriculture, and the growth of Physiology, are not outward things; they are all *conditions of thought.* The mind moves forward, and the external results are but the signals and registers of its march.

35. And these results are of the mightiest import. The discoveries of Gravitation, of Oxygen, of the Circulation of the Blood, of Vaccination, Anæsthetics, and Photography—the invention of the Mariner's Compass, of Gunpowder, the Printing Press, the Chronometer, the Steam Engine, and the Electric Telegraph, have reconstructed human relations; they are steps of advancement in which the whole world is implicated. But great as are the material revolutions which they have produced, they have a more momentous significance as the first glorious fruitings of the growth of knowledge. They are witnesses of what

their future? How are education and history to be regarded? 33. What is its relation to the mind? 34. In what does the progress of science consist? 35. What

can be accomplished by the earnest, persevering study of nature: they are prophetic of a new dispensation of the intellect—of a wider and nobler culture, in which the living universe of God shall neither be contemptuously passed by, nor assigned an inferior place in courses of study.

36. **The Demand of the Age.**—We cannot better close these observations on the nature and influence of science, than with the following extract from Prof. LIEBIG: 'The great desideratum of the present age is practically manifested in the establishment of schools in which the natural sciences occupy the most prominent place in the course of instruction. From these schools a more vigorous generation will come forth, powerful in understanding, qualified to appreciate and to accomplish all that is truly great, and to bring forth fruits of universal usefulness. Through them the resources, the wealth, and the strength of empires will be incalculably augmented; and when, by the increase of knowledge, the weight which presses on human existence has been lightened, and man is no longer overwhelmed by the pressure of earthly cares and troubles, then, and not till then, will his intellect, purified and refined, be able to rise to higher and higher objects.'

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is said of the great discoveries? What do they show? 36. What does LIEBIG state to be the requirement of the age? What would be the effect of such schools?

# PART I.

# CHEMICAL PHYSICS.

## CHAPTER I.

### OF SOME PHYSICAL CONDITIONS OF MATTER.

### § I. *Matter and Force.*

**37. Matter.**—Whatever occupies space and is revealed to our senses, is termed *matter*. Different kinds of it, as wood, water, air, are called *substances;* and any limited portion of it is called a *body*. The properties of matter are the characters by which it is known; and these may be either *general*, as those which belong to all matter, or *specific*, those which serve to distinguish one body from another.

**38.** Bodies are of two kinds, *simple* and *compound*. Compound bodies are such as can be decomposed or separated into simpler parts or *elements*. Simple bodies, on the contrary, cannot be thus separated. Water is a compound, and can be resolved into two invisible gases, but neither of these can be again decomposed. Brass may be separated into copper and zinc, but no one has yet been able to obtain from these anything besides copper and zinc.

**39. Persistence of Matter.**—Matter is *impenetrable*. As it is created in space, it must occupy space; two bodies cannot exist in the same place at the same time. Matter is thus persistent in space, and it is also persistent in time;—it is *indestructible*.

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37. What is said of matter and its properties? 38. How are bodies divided? Give examples. 39. What can you say of the indestructibility of matter? 40. Give ex-

There is no evidence that in the course of nature, or by any of the operations of art, matter is either called into existence or annihilated. It may be changed from state to state thousands of times without the smallest loss. A pound of ice converted into water or into steam continues to weigh exactly a pound. When fuel is burned, or water disappears by evaporation, or our own bodies are resolved into earth and air, it is only the migration of matter through the circle of natural transformations. Forms alone are destroyed—matter remains imperishable.

40. **Changes of Matter.**—The universe is everywhere in motion. The atmosphere is agitated by winds; the world of waters is in perpetual circulation; plants and animals spring from the earth and air and return to them again; all substances around us are undergoing slow transformations; the stony records of the strata are but histories of past revolutions; our ponderous earth shoots swiftly along its orbit, while the mighty sun, with all his attendant planets, is sweeping on forever through shoreless space. Nothing around or within us is absolutely at rest.

41. **Force.**—That which moves matter and produces change is called power, or *force*. The causes of the foregoing changes are called the forces of nature. Thus the Force of Gravity draws a piece of iron to the earth; Cohesive Force holds its particles together; Mechanical Force shapes it; Heat Force melts it; and Chemical Force rusts or dissolves it. Matter and force are inseparable; we know nothing of force except through matter, and nothing of matter except by its forces.

42. **Physical Changes.**—Those various alterations of place, form, and quality which bodies undergo without destroying their distinctive properties are termed *physical changes*. Thus iron may be cut into nails, rolled into sheets, drawn into wire, melted or magnetized, but through all these changes it still remains iron. Water changes its form, becoming a solid or vapor, but its peculiar composition as water remains unaltered. Gravity, cohesion, light, heat, electricity, and magnetism are the forces chiefly concerned in producing these changes, and are therefore called *physical forces*. That branch of science which treats of their effects is termed *Physics*.

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amples of the changes of matter. 41. What is force? Mention the effects of various forces. 42. What are physical properties? Physical changes? 43. What

**43. Chemical Changes.**—If iron be rusted, burned, or dissolved, it undergoes another and a deeper change; its peculiar properties are destroyed, and the metal disappears. In common combustion air and fuel are both changed, and new substances are produced. These are examples of *chemical changes*, such as are going on constantly around us; indeed, nature is a vast laboratory where they are incessantly taking place upon a stupendous scale. Chemistry considers the composition of matter, the nature of its elementary parts, the properties of the compounds formed from them, and the forces by which its various combinations and decompositions are produced.

**44. Chemical Physics.**—Physical forces and conditions have so powerful an influence over chemical action that some knowledge of them is indispensable to the chemical student. The progress of inquiry has, moreover, shown that the various forces are far more intimately related to each other than was formerly supposed, so that to understand them in the best manner they must be presented together. Accordingly, under the title of *Chemical Physics*, we first treat of those physical agencies which are most intimately connected with the subject of Chemistry.

## § II. *Gravity and Weighing.*

**45.** One of the simplest facts of observation is that bodies are drawn down to the surface of the earth with power. The attractive force which produces this effect is called *Gravity*. It acts between masses of matter of every kind, and at all distances; the earth, sun, moon, and all the heavenly bodies, thus influence each other. The various objects upon the earth's surface are not only powerfully attracted by the mass of our globe, but, in an infinitely lesser degree, they also attract it; and it has been further demonstrated that they also attract each other. A pair of leaden balls two inches in diameter were attached to the ends of a rod which was suspended in the middle by a fine wire, Fig. 1. Two other balls of lead, a foot in diameter, were placed upon a revolving platform, and when the larger and smaller balls were brought near together, they were mutually attracted, as was shown by the motion of the

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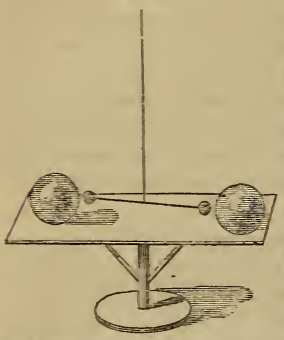
is the peculiarity of chemical changes? What does chemistry consider? 44. What has physics to do with chemistry? 45. What is the effect of gravity? Its extent?

rod. The force exerted did not exceed the twenty-millionth of the weight of the lesser ball, but was sufficient to slightly twist the wire, and give rise to a small oscillatory movement. The seemingly inert masses were thus proved to be alive with power.

FIG. 1.



Mutual attraction of leaden balls.

The force of gravity is proportional to the quantity of matter; that is, if the earth had twice its present mass its attraction would be doubled, and if but one-half its mass, its force would be only half as great. So with any body on the earth, the force with which it is attracted increases or diminishes in exact proportion to its quantity.

**45. This force gives rise to Weight.**—If a body, instead of being allowed to fall, is supported, its tendency to descend is not destroyed. It is drawn downward with the same force, but as it is resisted, and at rest, the force takes the shape of pressure. This downward pressure of bodies is called their *weight*. The weight of a body is the force it exerts in consequence of its gravity, and, as this force depends upon the quantity of matter, it is clear that if the mass be doubled, the weight will be doubled; if the mass be halved, the weight will be halved. Weights are therefore nothing more than measures of the force of gravity in different objects. Thus we discover the close connections and dependencies of all things. The same force which controls the mighty system of celestial orbs, measures quantities of matter in the daily transactions of business life.

**47. Standard Weights.**—The operation of *weighing* consists in estimating the force with which any given body is attracted toward the earth by comparing it with other masses of matter already weighed and marked according to some fixed standard, as Troy, Avoirdupois, or French weight. These standard scales are quite arbitrary, there being no natural starting-point, or unit. The grain weights were originally grains of wheat. The scales estab-

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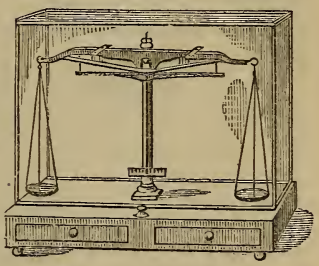
Describe the experiment. To what is this force proportional? 46. What is the cause of pressure? What is weight? 47. What are standards of weight? How

lished in this country are capriciously arranged, while the French employ a decimal scale, which is far more convenient, and is gradually coming into use among men of science.

**43. Weighing Instruments.**—The instruments employed in familiar weighing are steel-yards, springs, and scales, or balances. The chemical balance, Fig. 2, used for analysis, consists of an inflexible bar, delicately poised at a point exactly midway between its extremities, from which the scale-pans are suspended. Its beam rests upon a fine edge of hardened steel, which is supported by a flat plate of polished agate. This beam oscillates toward the earth just as the rod in the preceding experiment oscillated toward the larger balls. Such a balance is as indispensable to the laboratory of the chemist as the telescope is to the observatory of the astronomer. The foundations of the science are numerical laws, which could never have been arrived at except by its means. Prof. LIEBIG says, 'The great distinction between the manner of proceeding in chemistry and natural philosophy is that one *weighs*, while the other *measures*. The natural philosopher has applied his measures to nature for many centuries; but only for fifty years have we attempted to advance our natural philosophy by weighing. For all great discoveries chemistry is indebted to the balance, that incomparable instrument which gives permanence to every observation, dispels all ambiguity, establishes truth, detects error, and guides in the true path of inductive inquiry.'

FIG. 2.



The Chemical Balance.

## § III. *Comparative Weight—Specific Gravity.*

**49.** Weight, as thus far noticed, involves only the simple idea of gravity, and is termed *absolute* weight; it has no reference to

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does the French differ from other weights? 48. What is the construction of the chemical balance? How does chemistry differ from natural philosophy? What does LIEBIG say of the balance? 49. How is bulk related to weight? What cases

bulk or volume; yet bodies differ very much in their density, or the quantity of matter which they contain in a given bulk. Thus, a pound of cork exactly counterpoises a pound of lead, though the former occupies forty times as much space as the latter. So 100 cubic inches

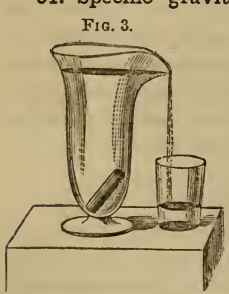
| | Pounds. | Grains. |
|---|---|---|
| Of Hydrogen weigh | | 2.14 |
| " Air " | | 31 |
| " Water, " | 3.604 | |
| " Iron " | 28.11 | |
| " Platinum " | 75.68 | |

Platinum, the heaviest body we know, is thus nearly a quarter of a million times heavier than an equal bulk of hydrogen, the lightest of known substances.

**50.** We now proceed to connect bulk with weight, to find, not the absolute gravity of a substance, but its weight compared with another body of equal size, that is, its relative, or *specific* gravity. Any solid substance when immersed in water displaces a volume exactly equal to its own bulk, and, at the same time, loses a portion of its own weight just equal to that of the volume of water displaced. Water, found everywhere upon the globe, and easily purified by distillation, is thus taken as the unit of comparison for solids and liquids. But variations of temperature alter the bulk of bodies, therefore sp. gr. is taken at the standard of 60°.

**51. Specific gravity of Solids.**—Fill a vessel with water, Fig. 3, and drop in it a piece of sulphur which has been weighed. A quantity of water will then escape into the dish below, equal in bulk to the sulphur. Weigh the escaped water in the lesser vessel. If the sulphur weighed two ounces, the water will weigh an ounce. That is, the sulphur weighs twice as much as an equal volume of water; its specific gravity is, therefore, 2. The best plan, however, is to suspend the solid to the scale-pan of a balance by a fine thread, or hair, and then

FIG. 3.

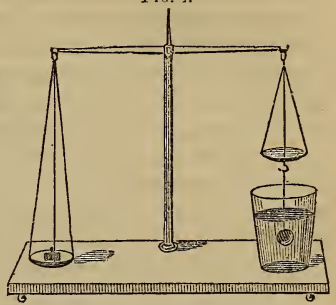


The solid displaces its bulk of water.

are given of the range of weights? What are the relations of platinum and hydrogen? 50. What is specific gravity? What is the principle upon which it depends? 51. What is shown by Fig. 3? How is the specific gravity of solids ob-

counterpoise it, or get its weight in the air. Immerse the suspended body in a vessel of distilled water, Fig. 4, and as it weighs less, remove weights enough from the opposite scale-pan to restore the lost equipoise. Now divide the original weight in air by the loss in water, and the quotient is the specific gravity of the substance. For instance, a piece of lead weighs in air, 820 grains, and loses in water 71 grains. The weight in air divided by the loss in water, gives 11.5 as the specific gravity of the lead.

Fig. 4.



Weighing a substance in water.

**52. Specific gravity of Liquids and Gases.**—Procure a small bottle and make a fine mark with a file and ink upon its neck. Counterpoise it in the balance. Fill to the mark with distilled water at 60° and weigh it. Empty and fill again with the liquid, the specific gravity of which is required. Its weight, divided by that of the water, gives the desired result. Suppose the bottle holds a thousand grains of pure water; it will be found to hold 1,845 grains of sulphuric acid, which therefore has a sp. gr. of 1.845. For 1000 : 1.000 : : 1845 : 1.845. It will hold 13,500 grs. of mercury, the sp. gr of which is hence 13.5; or 1,030 grs. of milk, sp. gr. 1.03. In practice it is usual to employ a bottle, Fig. 5, holding exactly 100 or 1,000 grains of distilled water at 60°, which shows the result at once without calculation. The specific gravity of gases is obtained in a similar manner. A flask or globe suspended from the arm of a balance is weighed when empty, and again when filled with air. This gives the weight of air, which is taken as unity. Other gases are then substituted for the air, and their comparative weights ascertained. Gases are subject to variations of density, not only by alterations of temperature, but by changes of atmospheric pressure; these

Fig. 5.

Sp. Gr. Bottle.

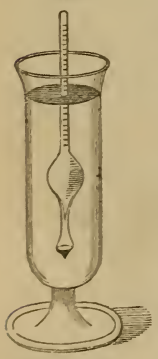
tained? 52. How is the specific gravity of liquids obtained? of gases? 53. How

weights are therefore taken at the standard barometric pressure of 30 inches.

53. **Specific gravity of Soil.**—The specific gravity of soil, or any other substance in powder, is obtained as follows: Counterpoise a thousand-grain bottle and weigh into it 150 grs. of soil to be tested. Fill with water and weigh again; water and soil give, say 1,096 grs., 150 of them are soil and 946 water; consequently 54 grs. of water have been displaced by 150 grs. of soil. The calculation is then easy, 54 : 1.000 : : 150 : 2.777 sp. gr. of the soil. In practice a precaution is to be observed. The soil contains air among its particles, which would vitiate the result. To obviate this, fill the bottle but half full of water at first, and shake it well with the soil; the air escapes, and the bottle may then be filled with water.

54. **Hydrometer.**—Take a tumbler, or a light slender-necked bottle, loaded with some shot, and float it in pure rain-water; it will sink to a certain depth, which may be accurately marked upon the glass. If now placed in brine or milk, the mark will stand above the surface; the vessel not sinking so deeply as before, because the liquids are heavier. Place it in alcohol, and the mark will disappear below the surface; it sinks deeper than at first, because the liquid is lighter than water. Instruments arranged on this principle, and called *Hydrometers* or *Areometers*, are used to measure the density of liquids. They usually consist of a glass stem, Fig. 6, terminating in a bulb below, loaded with shot or mercury, and floating in a narrow glass vessel, containing the liquid to be tested. Scales are fixed within the stem, zero being the point at which the instrument sinks in distilled water at 60°. In lighter liquids it sinks deeper, and the scale ascends from zero. In heavier liquids it floats higher, and the scale is reversed. These scales are arbitrary and different in the various instruments. Tables accompany them, so that we see at a glance the sp. gr. which corresponds to any number upon the scale. Instruments of this kind are much used by manufacturers and dealers, to determine the density or strength of liquors, syrups, oils, lyes, &c.

Fig. 6.



Hydrometer.

can we get the specific gravity of soil? 54. Describe the hydrometer. Why

55. Specific gravity is among the most important of the physical properties of bodies. It affords an important means of identifying them. The mineral iron pyrites, for example, is in color almost exactly like gold, and is frequently mistaken for it. But they are at once distinguished by the difference in specific gravity, an equal bulk of gold being nearly four times heavier than pyrites. So if gold is debased by alloying it with a cheaper metal, the specific gravity promptly detects the fraud. The proportion of alcohol in spirituous mixtures, the richness of milk, the strength of various solutions employed in the arts, and the identity and purity of many substances are determined with more or less accuracy by finding this property.

## § IV. *Minute Constitution of Matter.*

56. From the force which acts between masses at all distances, we now pass to the study of another class of forces which only come into play when bodies are in contact. They seem to pertain to the interior structure of substances, and hence before treating of them, it becomes important to inquire what that inner mechanism is, or how matter is constituted.

57. **Porosity of matter.**—If we place a little water upon chalk or cloth, it disappears; in a certain sense it penetrates them, but it does not enter the solid particles; it only passes into vacant places termed *pores*. Not only loosely composed substances, as soil and flesh, but wood, rocks, stones, and even dense metals have the same porous texture. A pressure of a single atmosphere is sufficient to drive the liquid metal mercury through the pores of wood. Water gradually works its way through beds of rocks in the earth, and stones taken from the bottom of the sea at considerable depths, are found penetrated by it to their very centre. Mercury passes through lead, and water has been also forced through the pores of gold. So, that though matter is essentially impenetrable, it is also universally porous.

58. **Interior movements of bodies.**—If a closed India-rubber bag filled with air be squeezed, it will be compressed into less bulk; that is, the particles of air will be forced nearer together.

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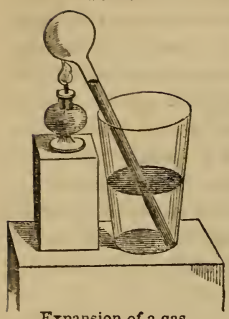
must its scales be differently placed? 55. What are the uses of specific gravity? 57. How extensive is the property of porosity? 58. Describe the illustrations of

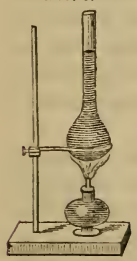
Fig. 7.



Expansion of a gas.

If alcohol and water be commingled, the mixture occupies a smaller space than did the separate liquids; their particles have therefore approached closer to each other. If iron, or the densest of all metals, platinum, be hammered, it will be driven into less compass, the metallic particles being forced into closer relation. A glass bulb with an open tube is partially filled with water, and inverted in a vessel of the same liquid, so that the upper space will enclose air, Fig. 7. If, now, heat be applied to the bulb, the air is expanded and the water pressed down. If the bulb be filled with water up to a point marked upon the neck with ink, Fig. 8, and the water heated, it will expand and rise above the mark. Or if a copper ball, which just slips through a ring, be heated, it is enlarged so that it rests upon the ring, and will not pass through it, Fig. 9. But if we remove the lamps and wait awhile, the heat gradually escapes; the air shrinks to its former compass; the water falls again to the ink-mark, and the ball drops through the ring.

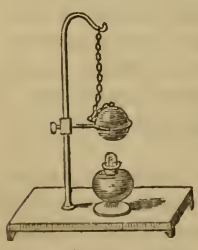
Fig. 8.



Expansion of a liquid.

**59.** These expansions and contractions, exhibited by matter in its three-fold state, are the result of movements among the constituent particles, which first recede from each other, and then come together again. Nor do these movements of the particles occur at random; they are strictly regular. A definite increase of pressure upon substances occasions a corresponding approach of their particles; as heat is steadily applied, dilation steadily follows, and if they are subjected to cold, contraction occurs, the distance between the particles diminishing with every degree of descending temperature.

Fig. 9.



Expansion of a solid.

**60. Atoms and their Interspaces.**—From these facts, it is concluded that matter consists of exceedingly minute particles which

the interior movements of bodies. 59. What is said of the regularity of these movements? 60. How is matter supposed to be constituted? What are atoms?

are never in absolute contact, but are surrounded by unoccupied spaces, in which they are held by the action of internal forces. These ultimate, separated, material points, are called *atoms*, the word signifying an *indivisible* particle. Of their shape nothing is known. The intervals between them, it is supposed, are far greater than their diameters; indeed the grouping of the celestial orbs is often taken to represent the distribution of atoms in a solid substance. Sir JOHN HERSCHEL asks why the atoms of a solid may not be imagined to be as thinly distributed through the space it occupies, as the stars that compose the nebula; and compares a ray of light penetrating glass to a bird threading the mazes of a forest.

**61.** For the sake of precision, it is convenient to restrict the term *particles* to those minute portions of bodies which are appreciable by the senses, or the microscope, while the word *atoms* designates those infinitely smaller parts of matter of which we have no experience, being purely hypothetical creations. The term *molecule* is frequently used as the equivalent of atom, but it more properly signifies a cluster, or group of atoms, though still far more minute than sensible particles. The words *pores* and *interstices* are generally used as equivalent, but it would be well to confine the former term to those openings among particles which admit the passage of liquids, and limit the latter to those far smaller vacancies among ultimate atoms which are traversed by heat, light, and electricity.

**62. Divisibility of matter.**—The division of matter may be carried to an amazing extent. Gold may be drawn out as a coating upon silver wire until the 492-thousand-millionth part of an ounce is still visible, with its proper metallic color and lustre. It has been estimated that in a drop of the blood of the musk-deer, such as would remain suspended upon the point of a fine needle, there are one hundred and twenty millions of globules. But these examples of the divisibility of matter bring us only to the threshold of a world of wonders. Microscopic researches have introduced us to a realm of life peopled with animate beings, which are born, grow, reproduce their kind, and die; and yet so minute, that many millions of them heaped together would not exceed in size a grain of sand. EHRENBERG estimates that there were forty-one thousand

How are they believed to be related to their interspaces? 61. What are particles? How do atoms differ from particles? How is the term molecule used? How are the terms pores and interstices used? 62. What illustrations are given of the di

millions of their fossil shells in a single cubic inch of slate; and yet these tiny beings are supposed to be endowed with organs of digestion, circulation, respiration, and locomotion—these to be made up of complex organized parts—these of chemical elements, and these again of ultimate atoms!

**63. The three states of matter.**—Under the influence of various molecular forces, bodies assume the three-fold state of solids, liquids, and gases. In solids, the atoms are so rigidly held together by attraction that the body retains its figure. In the liquid state, attraction is so feeble that the particles slide over one another, and the body takes the flowing condition; and in the gaseous or aëriform state, the repulsive forces predominate, driving the particles asunder. Most substances are capable of being changed from one of these states to another, and some of them, as water and sulphur, take on all three conditions. The term *vapor* is applied to those gases which readily relapse into the solid or liquid form, as steam, vapor of iodine, &c. We will now notice some of those forms of force which are exerted between bodies only when in contact, and which are known as *molecular attractions.*

## § V. *Molecular Attractions.*

**64. Cohesion.**—Though the atoms of a solid are separated, yet it does not crumble to pieces. They are held together by a force which reaches across their interstices and binds them in a fixed relation. This force is the *attraction of cohesion.* It exists only between particles of the same kind, and gives to bodies solidity and form. The hardness, elasticity, brittleness; malleability, and ductility of solids are the result of various unknown modifications of cohesive force. There is also a mutual attraction among the particles of liquids. In a drop of liquid, cohesion attracts the particles into a rounded figure, against the influence of their weight, which would spread them out; pendant drops still further exemplify the same force.

**65. Adhesion.**—Adhesion is the force which unites *dissimilar* bodies and is exerted between substances of all kinds. The sticking of chalk to a blackboard, of metallic amalgams to the backs of

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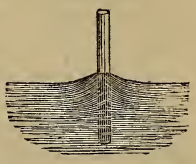
visibility of matter? 63. What are the three states of matter? What is the condition of their atoms? 64. What holds the atoms of a solid together? What properties of solids are due to cohesion? What is said of the cohesion of liquids?

looking-glasses, of glue to wood, and of mortar to bricks and stones, are familiar examples of adhesive force.

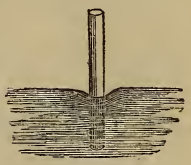
**66. Adhesion of liquids to solids.**—If a glass rod be dipped in water, the liquid will rise round it above its level in the vessel, Fig. 10, and when withdrawn, it will be *wet*. But if the same rod be dipped in mercury, there is an apparent repulsion, Fig. 11, and the rod when withdrawn is *dry*. If a rod of gold be dipped in the mercury it is wetted, or covered with a mercurial film. The wetting in this case shows an attraction between the liquid and the solid, and that it is sufficiently strong to produce adhesion. But there may be attraction without wetting; glass is not wet by mercury, and still they are attracted, as may be easily seen. Suspend a flat, circular plate of glass to the arm of a balance, counterpoise it, and lower the plate, Fig. 12, over a cup of mercury. No matter how near the glass approaches, while there is no contact, there is no attraction. But as soon as they are made to touch, a slight adhesion occurs,—sufficient to lift a portion of the mercury above its level in the vessel, the amount of which may be exactly measured by the number of weights required to be placed in the opposite scale-pan to separate them.

Fig. 10.



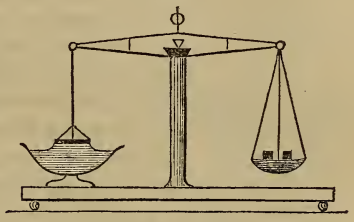
The glass rod in water.

Fig. 11.



The glass rod in mercury.

Fig. 12.



Attraction of glass and mercury.

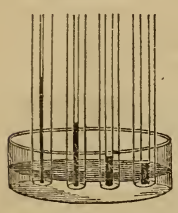
**67. Conditions of Wetting.**—If the adhesive force of any solid for any liquid *exceeds half* the cohesive force of the liquid particles for each other, the solid will be wet. Thus, the adhesion of gold for mercury, and of water for wood *exceeds half* the cohesive force of the mercurial and watery particles for each other, consequently water wets wood, and mercury wets gold. But if the adhesion of the solid be *less than half*

65. What is adhesion? 66. What is the effect if a glass rod be dipped into water? Into mercury? What, if a rod of gold be dipped into mercury? What does the wetting show? How may adhesion be shown to exist when there is no wetting?

the cohesion of the liquid, wetting does not follow contact, as is exemplified by glass and mercury.

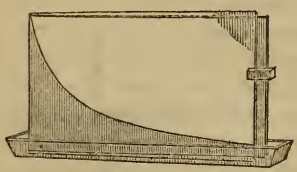
**68. Capillary Attraction.**—If glass rods with small apertures, open at both ends, Fig. 13, be dipped in water, the liquid immediately rises through the orifices to a height which increases in proportion to the smallness of the openings. The same thing may also be beautifully exhibited by placing two plates of glass, Fig. 14, upon their edges in a dish of colored water, one end being joined, and the other slightly separated. The influence of the gradually approaching sides of the glass in attracting the liquid upward is seen in the course of the curve. From the circumstance that this effect is best produced by tubes with very fine apertures, the attraction that causes these phenomena is called *Capillary*, (from *capillus*, a hair.)

Fig. 13.



Capillary tubes.

Fig. 14.



Rise of liquid between plates.

**69. Reversed Capillarity.**—If now a glass tube be dipped in mercury, we have again a disturbance of liquid equilibrium, but the effect is reversed. The interior column of mercury is depressed below the outside level, and its surface exhibits a convex shape, as seen in Fig. 15. The same thing occurs if the tube be greased and plunged in water, and in all cases where the liquid cannot wet the solid. The common belief that depression in this case (as in that of the glass and mercury) is caused by repulsion, is quite erroneous. We have proved (29) that, instead of repulsion, there is a strong attraction between glass and mercury. The reversed capillary action simply results from the preponderance of the cohesive over the adhesive force. In every body of fluid, each particle is kept in place by the mutual action of all the surrounding particles. But if a column of fluid be separated from

Fig 15.

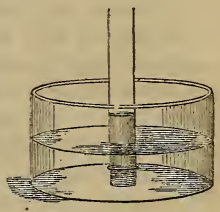
Convex liquid surface.

67. When will wetting occur, and when not? 68. Describe Figures 13 and 14. What name has been given to this effect, and why? 69. Explain Fig. 15. What is

the surrounding mass by interposing the walls of a tube, *the sides of which exert no equivalent adhesive force*, the cohesion of the mass below draws down the upper and outer particles, and produces a roundness or convexity at the top.

**70. Osmose.**—Tie a piece of moistened bladder tightly over the end of a tube, place it in a vessel of water, and then fill it with alcohol up to the level of the outer liquid. The fluid in the tube will shortly begin to ascend, and may rise to a considerable height, Fig. 16. The external water passes through the membrane and mixes with the alcohol, while, at the same time, a feeble current of alcohol flows the other way and commingles with the water. When different liquids are separated by a membrane in this manner, the one is transmitted fastest which wets the barrier most perfectly. DUTROCHET, who first drew attention to this matter, named the inflowing current *endosmose*, and the outflowing one *exosmose;* but these terms are lately less employed, and the phenomena are now known simply as *osmose*, from a Greek word signifying *impulsion*. The principle involved is a modification of capillary attraction. The pores of the bladder are short capillary tubes, into which water finds its way because it can wet the walls of the pore. Osmose is thus a result of the force of adhesion (66).

FIG. 16.



Osmose of liquids.

**71. Conditions of continuous Flow.**—A capillary tube, however fine it may be, will not cause the liquid within it to overflow; but if the liquid be removed from the top of the tube by evaporation or otherwise, the capillary force continues to supply it, and thus maintains the current. This may be seen in the wick of a lamp, when the oil is burned away and continuously supplied. If a small bladder be tied tightly to a tube, which is open at both ends and bent, as seen in Fig. 17, the

FIG. 17.

Osmose producing a continuous flow.

the cause of this? 70. Describe Fig. 16. What is osmose? Upon what does it probably depend? 71. How may osmose be made to produce a continuous flow?

bladder and part of the tube being filled with alcohol and submerged in water, osmose will set in and the liquid rise and overflow drop by drop into the cup, the motion continuing till the liquids are uniformly commingled. These principles probably afford an explanation of the flow of sap in plants, and the circulation of blood and nutritious juices in animals.

**72. Adhesion of gases to solids.**—If iron filings are gently dusted over the surface of water, they float, though iron is eight times heavier than water. This is because of the adhesion and condensation of a layer of air upon their surface, which prevents the water from wetting them. The condensed air around the particles forms a capillary cavity, and thus displaces a large volume of the liquid in comparison with that of the solid. Insects walk upon water and skim over its surface, because the air adhering to their feet forms capillary cavities, and prevents them from becoming wetted.

**73. Osmose of gases.**—The adhesion of gases to solids gives rise to currents, which pass through porous bodies with considerable power and velocity. Close the end of a glass tube with wet plaster. After it is dry, if the tube be filled with hydrogen, and its open end introduced into a vessel of water, the liquid rises rapidly. The hydrogen escapes outward through the porous plaster, while at the same time air enters the tube from without. But nearly four volumes, of hydrogen escape for one of air which enters, and these are called the *diffusion-volumes* of hydrogen and air. The diffusion volume of gases depends upon their density. If a thin sheet of India-rubber be tied tightly over the mouth of a glass jar, and the vessel be then placed in an atmosphere of carbonic acid, movement slowly takes place; a little of the internal air escaping outward, while so large a quantity of carbonic acid is transmitted inward as to distend the membrane into a dome-shaped cap, (Fig. 19.) If the situation of the gases be reversed, an opposite movement takes place, and the elastic sheet is deeply depressed, as the figure indicates. This principle is

Fig. 18.

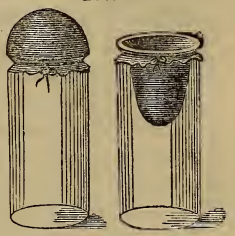
Osmose of gases.

What natural phenomena probably depend upon osmose? 72. What examples are given of the adhesion of gases and solids? 73. What does Fig. 18 show? What is meant by diffusion-volumes? What is said of the osmotic action of india-rubber sheets? Of the lung membranes? 74. How do gases behave when ex-

brought into play in atmospheric respiration. There is air on one side of the lung-membrane and blood on the other; oxygen is transmitted through the barrier from the air to the blood, and carbonic acid from the blood to the air.

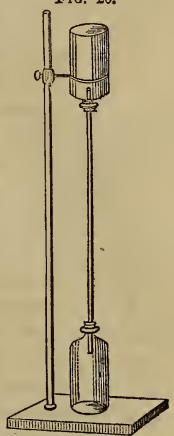
**74. Diffusion of gases.**—The vapor of water will rise and fill a confined vessel of air just as if the space were a vacuum, except that it will take a little longer time. When gases are exposed to each other, they will intermix or diffuse uniformly, even in opposition to gravity. If two jars be connected by a narrow tube, (Fig. 20,) and the lower filled with carbonic acid, while the upper one is filled with hydrogen, diffusion takes place through the narrow passage. The light hydrogen descends, and the carbonic acid, though twenty times heavier, rises, and they become equally mingled in both jars. Our atmosphere owes its stability to this principle; its constituents being perfectly intermingled. The baneful products of respiration, combustion, and decay, instead of accumulating, are incessantly dissolved away and dispersed in the atmospheric ocean.

Fig. 19.



Passage of gases through membranes.

Fig. 20.



Diffusion of gases.

**75. Adhesion of gases to liquids.**—When a liquid is poured from one vessel to another, the gases of the air adhere to the descending stream, are carried downward, and a portion of them remain combined with it. The force to be overcome by this adhesion is the elasticity of the gases, or the mutual repulsion of their particles. Pressure and cold lower the elastic force, and therefore favor absorption. As the temperature rises, adhesion is diminished, and hence the readiest means of driving out a gas from solution is by boiling.

**76. Diffusion of Liquids.**—Adhesion takes place between the particles of dissimilar liquids, causing their intimate mixture: thus a drop of ink will spread through a pint of water incorporating itself completely with the mass. This subject has been recently

posed to each other? Describe Fig. 20. How does this affect the atmosphere? 75. What is the effect of adhesion among liquids? 76. Describe liquid diffusion.

investigated by Prof. GRAHAM. With suitable precautions to prevent mechanical mixture, he placed small jars filled with liquids to be tested in larger ones containing distilled water as in fig. 21, and determined the amount of the inner solution that diffused into the water in a given time. Substances were found to differ greatly in diffusibility: chlorohydric acid is the most diffusible substance known. The equal diffusion of several solutions took place in the following times: Chlorohydric acid, 1; common salt, 2.33; sugar, 7; albumen, 49; caramel, 98. Substances thus tested are called *diffusates*.

FIG. 21.

Diffusion of liquids.

## § VI. *Solution.*

**77.** Whenever the force of adhesion of the particles of a liquid for a solid exceeds the *whole* cohesive force of the latter, the solid is not only moistened, but its cohesion is overcome and *solution* occurs; that is, the solid disappears—mixing uniformly with the liquid, which remains transparent. In this case the solid is said to have been *dissolved* by it, and the liquid employed is called the *solvent*. A liquid which dissolves one substance, may refuse to dissolve another, while substances insoluble in one liquid, are dissolved in others; and thus the hardest metals and minerals may be made to vanish and assume the transparent liquid form.

**78.** Whatever weakens cohesion favors solution. Thus, by powdering a substance, cohesion is partially destroyed and the surface increased; solution is consequently promoted. Heat, in most cases, contributes powerfully to solution, its effect being, as is supposed, to weaken cohesion, by increasing the distance between the particles of the solid; yet there are marked exceptions. Water just above the freezing point dissolves twice as much lime as at the boiling point, while the solubility of common salt seems hardly affected by temperature. Some substances increase in solubility regularly as the temperature increases; in many cases the solubility increases faster than the temperature, and in others it rises with the increasing heat to a certain point, and then declines, while the temperature continues to ascend.

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77. What is solution? Upon what does it depend? What is a solvent? 78. What

**79. Saturation.**—A liquid is said to be *saturated* when it has taken up as large a quantity of a solid as it can dissolve; in which case the force of cohesion between the particles of the solid is equalled by the adhesion of the solid and liquid to each other. The solvent power of liquids varies much. Water is the great solvent, and so general and important is its use, that in speaking simply of the solubility of a body, it is always understood.

**80. Precipitation.**—If the adhesive force of the solid and liquid can be overcome, cohesion takes place between the dissolved particles, which again unite as a solid. This change is called *precipitation*, and the solid formed, a *precipitate*. Precipitation may be effected in three ways: First, by removing the solvent, as in evaporation. Second, by modifying the solvent. For example, camphor dissolves in alcohol, but if water be added, it unites with the alcohol and so changes it that it can no longer hold the camphor in solution, which is precipitated as a white cloud, and afterward falls to the bottom of the vessel. Third, by adding a substance which combines with the dissolved body, forming an insoluble compound. Thus, if oxalic acid be added to lime water, it combines with the lime, precipitating it by the formation of an insoluble oxalate of lime. This property is an important one in chemical operations, as it enables us to separate the various constituents of a compound and detect the presence of a body when in solution with other substances.

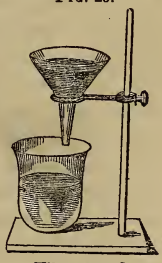
Fig. 22.

Fig. 23.

Fig. 24.

Paper filters.

Fig. 25.



Filter stand.

**81. Filtration.**—The process of separating precipitates by straining or passing the fluid through any porous substance, is called filtration. The chemist uses unsized paper for this purpose, which permits the liquid to ooze slowly through, leaving the solid substance behind. The filter paper cut and folded as in Fig. 22 takes the shape of Fig. 23, which adapts it to the glass funnel.

is the relation of cohesion to solution? Of heat? 79. In what does saturation consist? 80. What is precipitation? How may it be effected? How is it impor-

To prevent the adhesion of the paper to the sides of the glass, and thus facilitate the passage of the fluid, the filter is often plaited, Fig. 24. The funnel supporting the filter usually rests upon the stand, Fig. 25.

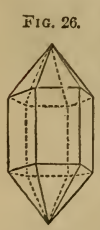
82. **Modes of Solution.**—Where there are mixed materials of variable solubility, with sufficient looseness of texture to permit a fluid to percolate through, one substance may be separated from the rest by being washed, or dissolved out. This is called *lixiviation*, a term first applied to the extraction of ley from ashes (*leaching*). The soluble principles of plants are extracted by *infusion*, which consists in pouring upon the substance a hot liquid. *Decoction* consists in boiling for a considerable time the materials to be separated. *Digestion* is the slow and gentle action of a solvent with warmth; and *maceration* the act of softening the substances by steeping.

## § VII. *Crystallization.*

### 1.—PRODUCTION OF CRYSTALS.

83. **Crystalloid and Colloid states.**—When the particles of many substances are loosened either by solution, melting, or otherwise, so as to be permitted freely to move, they tend to arrange themselves in regular geometrical forms, termed crystals, of which Fig. 26 may be taken as an example. All substances in which this tendency is marked are called *crystalloids*. But all substances do not crystallize, and the recent researches of Prof. GRAHAM, on the diffusion of liquids, have led him to conclude that there is another general state of matter which is definitely contrasted with the crystalloid, and which he terms the *colloid*, or glue-like. Water, acids, saline compounds, sugar, &c., are examples of crystalloids, while gum, albumen, jellies, and gelatinous silica are colloids. The crystalloids tend to assume hard, angular, unchangeable forms, while the colloids are of a soft gelatinous nature, very changeable, and characterized by rounded outlines. Crystalloid bodies predominate in the inorganic world; colloid in the organic. The new views have

FIG. 26.



Crystal of quartz.

tant? 81. What is filtration? How does the chemist effect it? 82. What is lixiviation? Decoction? Digestion? Maceration? 83. What occurs when the particles of matter are loosened? What are crystalloids? Colloids? 84. Give

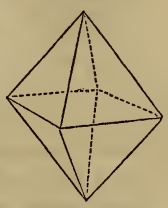
much interest, and will be referred to again in organic chemistry. We here consider only the crystalline state.

**84. Crystals in Nature.**—Nature teems with crystals. When it snows, the heavens shower them down (481), and ice is a mass of crystals, only so blended that we cannot distinguish them. Geology teaches that the materials of the globe were formerly in a melted state, so that in the slow process of cooling the opportunity was offered on the grandest scale for the formation of crystals. Hence, vast rocky systems have their constituents crystallized, and are known as the crystalline rocks. Metallic ores are nearly all crystallized, and immense regions of granite are but mountains of crystals.

**85. Crystals by Solution.**—Crystals may also be artificially produced in various ways. The readiest method of obtaining them is to prepare a hot, saturated solution of some substance that will dissolve more freely at a high than at a low temperature, alum, for example, and suffer it to cool, when crystals will make their appearance. The liquid from which they are formed is called the *mother liquor*. Crystals are of all sizes, from the minute particles of powder requiring a microscope to examine them, up to masses of crystallized quartz which are sometimes found weighing several hundred pounds. Artificial crystals are sometimes produced five or six inches in length; to obtain the largest and finest, the solution should be left quiet and inaccessible to dust.

**86.** Vibration may so disturb the process as to check the growth of those which have commenced, and start a second crop upon them. Crystals are seldom found perfect, being generally irregular, disguised, and distorted. Perfect alum crystals, for example, are regular octahedrons, Fig. 27, but Fig. 28 shows how they appear in the large vat of the manufacturer. Sometimes the attractions are so balanced that a jar or agitation is needed to start the action. In a perfectly still atmosphere, water may be cooled 8 or 10 degrees below the freezing point without congealing, but the vibration of the vessel produces a sudden crystallization of part of the liquid into ice.

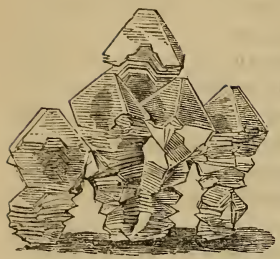
Fig. 27.



Crystal of alum.

examples of crystals in nature. Under what circumstances are they formed? 85. What is the best mode of preparing them? What is the mother liquor? What of their size? Of their perfection? Examples. 86. What is the influence

Fig. 28.



Masses of imperfect alum crystals.

Any solid body intruded into the liquid, by adhesion, may destroy the equilibrium and begin the play of the crystallizing attractions. Thus, threads are stretched across vessels containing solutions of sugar, and form a nucleus around which rock candy is crystallized.

**87. Crystals by Fusion.**—Nearly all bodies when melted and cooled take the crystalline form, though this may not be at first perceptible. The spaces left between the crystals which first form are completely filled up by the portions which solidify afterward, so that fracture reveals only a general crystalline structure, as may be observed in broken cast iron and zinc. Common sheet tin is beautifully crystallized, though nothing of the kind is apparent. If with weak acid we wash off the thin surface-film of metal, which had cooled too rapidly to crystallize, the structure will be revealed of a beautiful, feathered appearance. To obtain crystals by fusion, the excess of liquid must be removed from around those which are first formed. In this way beautiful sulphur crystals are produced. If a quantity of this substance be melted, and then allowed to cool till a crust forms upon the surface and sides of the vessel, crystals will be formed within, which may be seen either by breaking the vessel, Fig. 29, or by piercing the crust and draining off the interior liquid.

Fig. 29.

Sulphur crystals.

**88. By Sublimation and Decomposition.**—Solid substances vaporized (*sublimed*) may be condensed in the crystalline form, as iodine, sulphur, arsenic. Camphor thus vaporizes and condenses in brilliant crystals upon the sides of apothecaries' jars by the rise and fall of common temperatures. It is also possible, by decomposing a compound liquid or gas, to obtain one or more of its constituents crystallized. Various compound gases, when passed

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of agitation? Of a solid introduced into the solution? 87. What is said of crystallization by fusion? How are such crystals formed? Examples. 88. Give examples of crystals by sublimation. Decomposition. 89. What are the peculiarities of

through red-hot tubes, deposit crystals. Metallic solutions are decomposed by passing a galvanic current through them—the metals being deposited in the crystalline form.

**89. Amorphism.**—This term expresses the opposite of the crystalline state. *Amorphous* bodies are without any regular form or trace of crystalline structure, as common glass, flint, wax, glue, wrought iron. They fracture irregularly, in any direction, and are generally more soluble, and less hard and dense, than in the crystalline form. Diamond is crystalline carbon; charcoal and lampblack are amorphous carbon.

**90. Crystallization in the Solid state.**—Whenever particles are left free, they arrange into systematic crystalline shape, and this strong propensity of matter is manifested even in solids. Thus sugar candy, at first transparent and amorphous, after some time becomes opaque and crystalline. Glass, by long-continued heat, though it does not melt, becomes also opaque and crystalline (*Reaumur's porcelain*). Brass and silver, when first cast, are tough and uncrystalline, but when repeatedly heated and cooled, they become brittle, and show traces of crystallization. Even the little liberty the particles obtain by the motions of heating and cooling they improve to assume the crystalline condition. This is still better seen where the particles of bodies are thrown into motion by blows and vibration. Metals, by hammering, lose their ductility and tenacity and become brittle and crystalline. Coppersmiths, when hammering their vessels, frequently *anneal* them, to prevent their flying to pieces; that is, they heat them, and then allow them to slowly cool. Thus also bells, long rung, change their tone; cannon, after frequent firing, lose their strength, and are rejected; and so the perpetual jar and vibration of railroad axles and the shafts of machinery, gradually change the tough fibrous wrought iron into the crystalline state, weakening them and increasing their liability to fracture.

**91. Phenomena attending Crystallization.**—This change of state is usually attended by change of bulk. Water in freezing expands to a considerable degree, and with great power; 1,000 parts of water are dilated to 1,063 parts of ice; and the force exerted by the particles in changing positions is so enormous as to burst the strongest iron vessels. Heat is always manifested when

amorphous bodies? 90. How do solids become crystalline? Under what circumstances do copper, brass, and iron crystallize? 91. How is water changed by crys-

crystals are formed, in proportion to the rapidity of the change from the liquid to the solid state. Light has also occasionally been noticed to accompany the process, but its cause is not explained. Muddy and impure solutions often yield the largest crystals, and the presence of foreign bodies which do not themselves crystallize, may thus modify the form which the crystal assumes. For example, common salt usually crystallizes in the form of a cube, Fig. 41, but if urine be present in the solution, it takes the form of the octahedron, Fig. 46. When a crystal is broken, there is a tendency to repair it; it continues to increase in every direction, but the growth is most active upon the fractured surface, so that the proper outline of the figure is restored in a few hours.

**92. Purification by Crystallization.**—When substances crystallize their tendency is to separate themselves from any foreign bodies with which they may have mingled. For example, if common salt and saltpetre be dissolved in water and the solution slowly evaporated, they will crystallize in different forms, and thus separate. Crystallization is hence a means of purification, and is of great importance in detecting adulteration and producing genuine articles, both for chemical and manufacturing purposes.

### 2.—FORMS OF CRYSTALS.

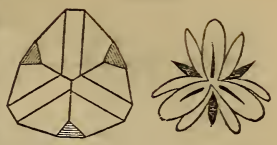
**93.** It is observed that in the living world curved lines and surfaces prevail. Drops of liquid assume the spherical shape, as also do the planets. We might, therefore, anticipate that dissolved substances, on being permitted freely to return to the solid state, would gather round a centre into spheres. Yet the shapes assumed under these circumstances are not curved, but *angular*, and are bounded on all sides by plane surfaces. This is well seen by comparing crystals with flowers, as in the ensuing figures.

**94. Symmetry in the plan of Nature.**—In the production of her most perfect forms nature manifests a principle of symmetry—a similarity in opposite and corresponding parts. In the higher animals this principle is manifested in the double set of members right and left, while the organs of flowers and the parts of crys-

tallization? What forces are manifested in crystallization? 92. How is crystallization a means of purification? 93. In what parts of nature do curved lines prevail? What would this lead us to expect of crystals? 94. What is symmetry? How manifested in the higher animals? What kind of symmetry is shown

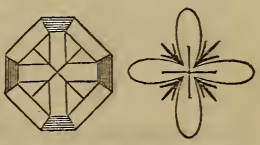
tals are also symmetrically distributed. Fig. 30 represents the summit of a pyramid-shaped crystal, as we look down upon it. It consists of three portions exactly similar to one another. The faces, with their angles, are repeated in *threes*. The companion figure shows that the same kind of symmetry is found among flowers, as in the lily tribe. This is called *three-membered*, or *triangular* symmetry, and is very abundant in both the vegetable and mineral kingdoms. Fig. 31 illustrates the *four-membered*, or *tetragonal* symmetry, which is abundant among minerals, but more rare among plants. The *five-membered*, or *pentagonal* symmetry, Fig. 32, is never found among perfect crystals, though it occurs abundantly in the animal and vegetable worlds. Fig. 33 represents another kind of symmetry, in which the opposite ends are exactly similar to each other, and also the opposite sides. This is two-and-two-membered, or *oblong* symmetry. And finally, in Fig. 34, we have the case of simple, or *bilateral* symmetry, in which the two *sides* are exactly alike, as illustrated in the higher animals.

Fig. 30.



Three-membered symmetry.

Fig. 31.

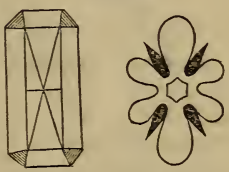


Four-membered symmetry.

Fig. 32.

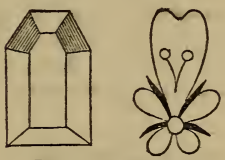
Five-membered symmetry.

Fig. 33.



Oblong, or two-and-two-membered symmetry.

Fig. 34.

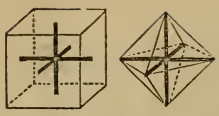


Bilateral symmetry.

**95. Axes of Crystals.**—There is an almost endless diversity in the forms which substances take when crystallizing, but through all a pervading plan has been discovered. The crystal is supposed to be traversed in

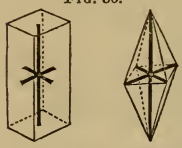
in Fig. 30? What is said of the prevalence of three-membered symmetry? Of four-membered? Of five-membered? Describe oblong symmetry. What is bilateral symmetry? Where does the parallelism fail? In what cases is it most

Fig. 35.



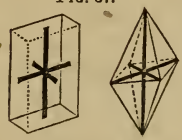
The regular system.

Fig. 36.



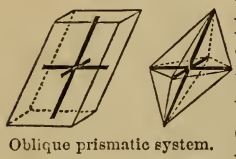
Square prismatic system.

Fig. 37.



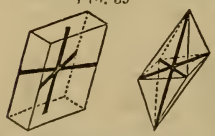
Right prismatic system.

Fig. 38.



Oblique prismatic system.

Fig. 39



Doubly oblique prismatic system.

different directions by lines termed *axes*. These lines of symmetry govern the figure, and the same axes may be preserved, while the forms built around them are endless.

**96.** Six primary systems have been discovered, the axes of which are represented by the large lines in the following figures. In each system they remain the same. The right-hand figures are seen to be derived from the left-hand by change of external form.

**97.** The *regular system*, Fig. 35, has three equal axes at right angles to each other. Crystals of this system expand equally in all directions by heat, and refract light in the ordinary manner. Common salt and iron pyrites are examples.

**98.** The *square prismatic system*, Fig. 36, has three axes all at right angles to each other, two of which are equal, while the third is of a different length. It expands by heat equally in *two* directions only, and splits the ray of light passing through it (*double refraction*), as do also the four systems remaining to be noticed (359). Examples: oxide of tin and cyanide of mercury.

**99.** The *right prismatic system*, Fig. 37, has three axes of unequal length, at right angles to each other. Crystals of this system expand unequally in the three directions of the axes. Nitre and topaz may be taken as examples.

**100.** The *oblique prismatic system* has

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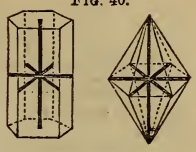
extensive? 95. What are the axes of crystals? What of their importance? 96. How many primary systems are there? How are they represented? 97. What is the arrangement of the axes of the regular system? 98. How are the axes disposed in the square prismatic system? How is it related to heat and light? 99. Describe the right prismatic system. Mention examples of it.

three axes, which may be unequal, Fig. 38. Two are placed at right angles to each other, and the third is oblique to one and perpendicular to the other. Sulphate of soda and borax are common examples.

Fig. 40.



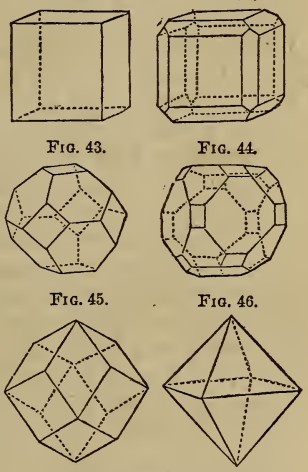
Rhombohedral system.

**101.** The *doubly oblique prismatic system* has three axes, which may be all unequal and all oblique, Fig. 39. Examples: sulphate of copper and nitrate of bismuth.

**102.** The *rhombohedral system*, Fig. 40, has four axes, three of which are equal in the same plane, and inclined at angles of 60°, while the fourth is perpendicular to all. Examples: quartz, Iceland spar, and ice.

**103. Cleavage.**—If we apply the edge of a knife to a piece of mica, it may be cleft into thinner plates, and these may again be separated into the thinnest films. Nearly all crystals will thus separate in certain directions, disclosing polished surfaces, and showing the order of formation of successive parts. This mechanical splitting of crystals is termed *cleavage*. Instruments for measuring the angles of crystals are called *goniometers*.

**104. Derivation of form.**—The cube, Fig. 41, may be taken to illustrate change of figure, and this is chiefly effected by replacing edges and angles by planes. The cube has eight edges and eight solid angles. If plane surfaces are substituted for the edges, we get the secondary form, Fig. 42. If we replace the solid angles by planes, we have the form Fig. 43. If both these replacements occur together, the more complex Fig. 44 results. If the edges of the cube be replaced until all traces of the




Transformations of the cube.

100. How does the oblique prismatic system differ from the preceding? 101. How are the axes arranged in the doubly oblique? 102. In the rhombohedral? Examples. 103. What is cleavage? 104. What example of the derivation of form is

original planes disappear, Fig. 45, the rhombic dodecahedron, is formed. And if the solid angles be replaced by planes to the same extent, we get Fig. 46, the regular octahedron.

**105.** We have said that the secondary or derived forms of crystals are almost innumerable. Six hundred modifications of the six-sided prism have been enumerated by Dr. SCORESBY, among snowflakes, while M. BOURNON, in a two-volume treatise, has delineated eight hundred different forms of the mineral calcite (carbonate of lime). HAUY has described a single crystal which had 134 faces.

**106.** The axes of crystals are not mere imaginary lines. The force which builds the crystal works unequally, and endows it with different powers in different directions. In those crystals where the axes are all equal, light, heat, and electricity are conducted equally in every direction. But where the axes are unequal, conduction of heat and electricity, hardness, elasticity, transparency, expansion by heat, and luminous refraction are correspondingly unequal, showing an actual difference of structure in the different directions; just as wood varies in qualities when tested with or across the grain. This perfect regularity of structure in crystals, by which they manifest different powers in different directions, can only be explained by supposing that attraction, in causing atoms to cohere in crystalline combination, does not act equally all around each atom, but between certain sides or parts of one atom and corresponding parts of another; so that when allowed to unite according to their natural tendencies, they always assume a certain definite arrangement. This property of atoms is called *polarity*, because in these circumstances they seem to resemble *magnets*, which attract each other by their poles (159).

**107. Isomorphism.**—Different substances may take the same crystalline form, and be substituted for each other, without changing that form. Thus carbon, gold, and copper, among the elements, and sulphide of lead, alum, and fluor spar, among the compounds, all crystallize in cubes or octahedrons which perfectly resemble each other. This property is called *isomorphism* (equal-formed). Isomorphous bodies also often closely resemble each other in chemical properties.

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given? 105. What is the extent of modifications? What did SCORESBY ascertain? M. BOURNON? HAUY? 106. What evidence is there that crystalline axes are real

**108. Dimorphism.**—It was formerly supposed that each substance crystallized in one peculiar form, which afforded an unerring clue to its identity; but this is not invariably the case. Some substances crystallize in two different forms, and are called *dimorphous* (two-formed). Thus, sulphur deposited from solution takes one form, and another when cooled from melting. Nitre crystallizes in large quantities in one shape, and in small quantities it takes another. Some few substances crystallize in three distinct forms, and are called *trimorphous.*

# CHAPTER II.

## CHEMICAL FORCES, LAWS, AND LANGUAGE.

### § I. *Chemical Attraction.*

**109.** We have seen the force of molecular attraction producing various interesting movements and changes, and at last overcoming the states of bodies so as to occasion that intimate combination of different kinds of matter called *solution.* But this attraction takes a still more powerful form, becoming so intense as altogether to destroy the properties of the substances engaged and give rise to new kinds of matter. The force which produces this class of effects is known as *affinity* or *chemical attraction.* Before considering it, however, we will notice the nature of the substances upon which it acts.

**110. Elements and Compounds.**—Modern chemistry has shown that there are about 64 *elements*, or different kinds of matter, which cannot, by any known process, be further separated or decomposed. Their names are given in the following table. Most of the material objects of nature are, however, *compounds*, formed by the union of these elements. Nature may thus be likened to a language, the elements to letters, and the compounds to words; and as a

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things? 107. What is isomorphism? 108. What is dimorphism? 109. What is the difference between solution and chemical attraction? 110. What is a chemical element? How many are there? What are most material objects of nature? What are compound bodies? How may the constitution of

few letters, by their infinite diversity of combination, give rise to innumerable words, sentences, and books, so a few elements produce all the boundless variety of natural objects.

**111.** In the following list of elements, those which are rare and comparatively unimportant are printed in italics.

| ELEMENTS. | *Symbol* | *Combining number.* | ELEMENTS. | *Symbol.* | *Combining number.* |
|---|---|---|---|---|---|
| Aluminum, | Al. | 13.70 | *Niobium* (Columbium) | Nb. | 48.80 |
| Antimony (Stibium), | Sb. | 129.00 | Nitrogen, | N. | 14.00 |
| Arsenicum, | As. | 75.00 | *Norium*, | No. | |
| Barium, | Ba. | 68.50 | *Osmium*, | Os. | 99.40 |
| Bismuth, | Bi. | 210.30 | Oxygen, | O. | 8.00 |
| Boron, | Bo. | 10.90 | Palladium, | Pd. | 53.20 |
| Bromine, | Br. | 80.00 | Phosphorus, | P. | 31.00 |
| *Cadmium*, | Cd. | 56.00 | Platinum, | Pt. | 98.60 |
| Cæsium, | Cs. | 123.40 | Potassium (Kalium) | K. | 39.00 |
| Calcium, | Ca. | 20.00 | *Rhodium*, | Ro. | 53.20 |
| Carbon, | C. | 6.00 | *Rubidium*, | Rb. | 85.36 |
| *Cerium*, | Ce. | 46.00 | *Ruthenium*, | Ru. | 52.11 |
| Chlorine, | Cl. | 35.50 | *Selenium*, | Se. | 39.70 |
| Chromium, | Cr. | 26.30 | Silicon, | Si. | 14.00 |
| Cobalt, | Co. | 29.50 | Silver (Argentum), | Ag. | 108.00 |
| Copper (Cuprum), | Cu. | 31.70 | Sodium (Natrium), | Na. | 23.00 |
| *Didymium*, | D. | 48.00 | *Strontium*, | Sr. | 43.80 |
| *Erbium*, | E. | | Sulphur, | S. | 16.00 |
| Fluorine, | F. | 19.00 | *Tantalum*, | Ta. | 68.80 |
| *Glucinum*, | Gl. | 4.70 | *Tellurium*, | Te. | 64.50 |
| Gold (Aurum), | Au. | 196.44 | *Terbium*, | Tb. | |
| Hydrogen, | H. | 1.00 | *Thallium*, | Tl. | |
| Iodine, | I. | 127.00 | *Thorinum*, | Th. | 59.50 |
| *Iridium*, | Ir. | 98.60 | Tin (Stannum) | Sn. | 59.00 |
| Iron (Ferrum), | Fe. | 28.00 | *Titanium*, | Ti. | 25.00 |
| *Lanthanum*, | La. | 46.00 | *Tungsten* (Wolfram), | W. | 92.00 |
| Lead (Plumbum), | Pb. | 103.60 | *Uranium*, | U. | 60.00 |
| *Lithium*, | L. | 7.00 | *Vanadium*, | V. | 68.50 |
| Magnesium, | Mg. | 12.16 | *Yttrium*, | Y. | |
| Manganese, | Mn. | 27.48 | Zinc, | Zn. | 32.60 |
| Mercury (Hydrargyrum), | Hg. | 100.00 | *Zirconium*, | Zr. | 22.40 |
| *Molybdenum*, | M. | 48.00 | * *Indium.* | | |
| Nickel, | Ni. | 29.50 | | | |

**112. Analysis and Synthesis.**—The separation of compound bodies into simpler ones is called *analysis*. A compound may consist of compounds, and the first analysis may give only its nearest or *proximate* parts, while the second shows its *ultimate* constituents, or elements. Thus flour may be decomposed into gluten, starch, oil, and water (*proximate analysis*); but these substances may again be resolved into their final elements (*ultimate analysis*). *Qualitative* analysis determines of *what* elements a compound consists; *quantitative* analysis ascertains their *proportions*. *Synthesis* consists in combining the elements into compounds; it is therefore the reverse of analysis.

* A Fourth new metal lately discovered by Spectrum Analysis.

natural objects be compared to a language? 112. What is analysis? Proximate analysis? Ultimate? Qualitative? Quantitative? What is synthesis?

**113. Affinity.**—The force brought into play in carrying on these changes is not manifested alike between all kinds of bodies; some exert it only in a feeble degree, and others powerfully. It seems to manifest a kind of preference or election, which induced the alchemists long ago to name it *affinity*. The term, however, is unfortunate, as it properly signifies resemblance or relationship, whereas in chemistry it is only the name of the force which produces chemical union.

**114. Conditions of its exercise.**—Like adhesion, this force acts only between unlike bodies. If the earth consisted of but one kind of matter, mercury, for instance, there might be gravitation and cohesion, but affinity would be impossible. It might be physically changed by freezing, melting, or vaporizing, yet it would remain mercury still. But if sulphur were added, it would combine with the metal, forming a new substance, a *compound*, and thus chemistry, which implies a plurality of elements, would come into existence.

**115.** However intimate the mixture of substances may be, their separate properties remain unchanged unless chemical action takes place. In the manufacture of gunpowder, its elements, charcoal, sulphur, and nitre, are separately reduced to a state of fine powder, then thoroughly mixed, moistened, and ground for hours with stones, and afterward intensely pressed and pulverized. But close as is the combination, it is only *mechanical;* water will wash out the nitre, and bi-sulphide of carbon dissolve the sulphur, leaving the charcoal. The particles are not brought within each other's attractions, and affinity still slumbers. But a spark of fire awakens it, the elements rush into combination and disappear, leaving in their stead a huge volume of gaseous matter.

**116. Changes wrought by Affinity.**—Newness of properties, either in color, odor, form, density, or some other quality, is a consequence of all chemical union. It may convert two solids into a liquid, two liquids into a solid, or even two gases into a solid. Thus, when black charcoal and yellow sulphur combine, the compound formed is colorless as water, and highly volatile. Sulphur and quicksilver unite to form the bright-red vermilion. Nitrogen

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113. What is meant by affinity? Why is this use of the term unfortunate?
114. How does the force of affinity differ from that of gravitation and cohesion?
115. How is the difference between combination and mixture illustrated?
116. What is said of the effect of affinity in changing the properties of bodies?

and oxygen are neutral and tasteless, separate or mixed; yet one of their compounds, laughing gas, is sweet, producing delirium when breathed; and another, nitric acid, is an intensely sour, corrosive poison: they are both invisible, yet they form a cherry-red gas. Carbon and hydrogen are odorless, yet they combine to produce our choicest perfumes. Mild and scentless hydrogen and nitrogen form the pungent ammonia; while suffocating and poisonous chlorine, united with a brilliant metal, gives rise to common salt. The last-mentioned compound strikingly illustrates the enormous power of affinity in producing condensation. Thus 24 parts, by measure, of common salt contain 25.8 parts, or *more than its own bulk*, of the metal sodium, besides 30 parts by measure of liquid chlorine. No known mechanical force could have produced this condensation, and yet affinity readily effects it;—the product, rock salt, being more transparent than glass.

**117.** There is, however, a gradation in these effects. Substances resembling each other are feebly attracted together, and only lose their properties partially; and the wider the difference, the stronger is the affinity, and the more complete the transformation. If the elements are very similar, the compound will show its parentage; if quite unlike, all traces of its derivation will be lost. Thus, iron and mercury form a compound whose metallic aspect immediately betrays its origin; but who, on looking at gypsum, would suppose it consisted of caustic lime and corrosive sulphuric acid.

**118. Affinities Unequal.**—The chemical force which binds together the constituents of a compound is definite, and, under like circumstances, remains always the same; but it varies in intensity among different substances. Thus, carbonic acid will combine with soda, forming carbonate of soda. But if acetic acid be brought into contact with this compound, it will drive off the carbonic acid and take its place, forming acetate of soda. Again, the affinity of chlorohydric acid for the soda is superior to that of the acetic acid; it will therefore expel it and form a new substance. Tables have been constructed, representing the order of affinities among different substances, but so many causes disturb the play of this force that they are of but little value.

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Illustrations. 117. When will this change be greatest? When least? Examples. 118. What is said of the variability of affinity? What will be the effect if acetic acid be added to carbonate of soda? Hydrochloric acid to acetate of soda?

**119. Displacement.**—Chemical compounds are formed in two ways. First, where the affinity is powerful, the substances combine directly when brought together. But by far the more frequent method, both in the laboratory and in nature, is where, in a body already formed, one of its ingredients is replaced by another substance, and a new compound results. The changes mentioned in the preceding paragraph are a series of displacements of this kind. This method of chemical action by *substitution* is very important, and will be again referred to.

**120. Commencement of chemical action.**—When some substances are brought into contact, chemical union instantly occurs; but in most cases another force, heat, for example, is necessary to commence the action. Thus, a heap of charcoal may remain exposed to the air for years unchanged; but, if heat be applied, it will arouse a chemical action between the charcoal and the oxygen of the air, which will continue till the entire mass is consumed. Phosphide of hydrogen, on the contrary, bursts into flame the moment it is exposed to the air.

**121. Influence of Cohesion.**—Cohesion obstructs the working of affinity. In very rare cases, as phosphorus and iodine, solids may directly combine; but, as a general principle, cohesion must be entirely overcome, either by melting or dissolving one or both the ingredients, before chemical action can take place. Solution is, therefore, one of the grand processes of the laboratory, and solvents have been found for all substances.

**122. The nascent state.**—The moment in which substances are liberated from union with each other is called the *nascent* (growing) state, and, at this time, they often enter into combinations which could not be formed under other circumstances. Nitrogen and hydrogen gases, if mingled, do not unite; but when set free at the same time, by the decomposition of vegetable matter, they readily combine to form ammonia. The chemical union of two substances is often effected by the bare presence of a third body, which remains unchanged during the process. This is termed *catalysis*, or contact action, and its causes are not understood.

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119. How does direct combination differ from combination by displacement? 120. How do substances differ in chemical energy? What force promotes it? Examples. 121. What effect has cohesion upon the play of affinity? Exceptions. What is said of solution? 122. What is the nascent state? Its relation

## § II. *Laws of Chemical Combination.*

123. **The Mathematics of Chemistry.**—When instruments of weighing had attained a sufficient degree of perfection, it was found that, however often matter might change its form, nothing was either gained or lost—that its quantity remained the same. But other results of the highest importance also followed. It was discovered, that the force of affinity, as well as that of gravitation, conforms to exact numerical laws; that there is a mathematical order in the domain of chemistry as absolute as that which reigns in the realm of astronomy. As the forces which govern the heavenly bodies cause them to complete their revolutions with infinite regularity and precision, so the chemical force which binds together the constituents of a compound, produces its results always in the same definite and unalterable proportions. This is the foundation principle of the science. When the composition of a sample of water, common salt, or lime, is once accurately determined, the knowledge applies to all water, common salt, and lime; and so of every other substance. Pure water consists of 8 parts, by weight, of oxygen, combined with 1 part, by weight, of hydrogen; and we can produce it by the union of its elements in these proportions, and no other. So potash invariably consists of 39 parts potassium and 8 oxygen; and common salt, of 35 chlorine to 23 sodium. Certain numbers, ascertained by experiment, and called *combining numbers*, express the proportions in which elements invariably unite to form all chemical compounds.

124. How marvellous is this order! The stones and soil beneath our feet, and the ponderous mountains, are not mere confused masses of matter; they are pervaded through their innermost constitution by the harmony of numbers. The elements of the wood we burn are associated in fixed mathematical ratios. In the violence of combustion, the bond that held them together is destroyed; they break away and rush into new combinations, but they cannot escape the law of numerical destiny. The burning

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to affinity? Give an example. What is meant by catalysis? 123. What important discoveries followed the introduction of the balance into chemistry? What is said to be the foundation of the science? Examples. What is the proportion of the elements in water? In potash? Common salt? What are combining numbers? 124. What is said of the constitution of all

candle gradually wastes away before us, dissolves in air, and passes beyond the reach of sight; but in that invisible region, forces are playing among its unseen particles with the same exactitude and harmony as among those which rule the constellations. And so is it with all chemical mutations. In the gradual growth of living structures, in the digestion of food, and in the slow decay of organic matter, no less than in its quick combustion, the transposition of elements takes place in rigorous accordance with the laws of quantitative proportion.

**125. The Chemical Chart.**—To represent these foundation facts of chemistry to the most impressible of the senses—the eye—and give the student the same advantage in the study of this science that is derived from maps in Geography and Astronomy, the author has prepared a Chemical Chart, which presents the laws of combination, in a great number of cases, in the simplest and clearest manner. The left column enumerates 15 of the most important elementary substances, and represents each by a square colored diagram. Single squares represent elements, but when joined together, as shown by the converging lines, they indicate compounds. As a separate color is thus assigned to each element of a compound body, its exact composition is exhibited at a glance. The areas of the diagrams correspond to the combining numbers, and thus represent relative quantities to the eye. The hydrogen square being smallest, the oxygen square is 8 times larger, the carbon square 6, and the chlorine 35 times larger. Diagrams of the same color have always the same size. Thus oxygen, wherever found, is seen obeying the law of its fixed proportions; its square is always of the same size, and so with all the other elements.*

**126. Equivalents.**—If we take equal quantities of two elements, we do not find that they possess equal powers of attraction.

* Chlorine, Carbon, Sulphur, and Phosphorus are represented upon the Chart by their natural colors. Fluorine, from its supposed resemblance to oxygen in properties, has an analogous tint; Nitrogen is of the color of the air (sky blue), of which it is the chief ingredient. Oxygen, as the sustainer of combustion, and the agent which changes the blood from a purple to a florid tint, is represented of a crimson color. The bases of the alkalies have various shades of blue, corresponding to the strength of the alkalies which they form. (The alkalies restore the blue vegetable colors discharged by acids.) Aluminum, the basis of clay, is of a clay color. Silicon, which is said somewhat to resemble carbon, is of a dark color. Iron forms green-colored salts, and manganese those of a rose color.

natural objects? 125. Why was the chemical chart devised? Describe it. 126. On what is the idea of chemical equivalents based? What example is given?

There is as much chemical energy or neutralizing power in one grain of hydrogen as in 8 grains of oxygen; and 35 grains of chlorine neutralize 8 grains of oxygen only equally well with 1 grain of hydrogen. Therefore, 1 gr. of hydrogen, 8 grs. of oxygen, and 35 grs. of chlorine, are of equal value chemically—in other words, they are *equivalents*. When two bodies combine with a third, as they are each equivalents of the third body, so are they also equivalents of each other, and unite together in exactly the same proportions. For example, 1 part of hydrogen combines with 8 of oxygen, and 35 of chlorine combine with 8 of oxygen, but 35 of chlorine is the very quantity which combines with 1 of hydrogen. Thus the proportion in which any two bodies combine with each other is that in which they combine with *every* other.

**127. Combining or equivalent numbers.**—To each chemical substance, therefore, is attached its fixed number, and these numbers are so mutually related, that no one can be changed without a corresponding alteration of the whole series. We may employ any scale, so the *relative* values are maintained. We adopt the hydrogen scale, which is, perhaps, the best for general teaching. As hydrogen combines in the smallest proportion of any element, it is assumed as 1, oxygen will then be 8, nitrogen 14, &c. As oxygen, however, has the largest range of affinity, it is more convenient, in laboratory work, to assume it as 100, in which case hydrogen becomes 12.5, and the other numbers are changed accordingly.

**128. Multiple proportions.**—When combinations occur in more proportions than one, the larger quantities are multiples of the smaller *by a whole number*. The compounds of nitrogen and oxygen furnish a beautiful illustration of this law. The proportion of nitrogen is the same in all: 14 parts of nitrogen to 8 of oxygen form a compound with one set of properties; twice 8 of oxygen gives another compound with different properties; thrice 8 produces still a different substance; 32 parts, another; and 40, or five times 8, yet another. (See *Chemical Chart.*)

**129.** The law of equivalents applies to compounds as well as to elements. The equivalent of a compound body is the sum of the equivalents of its elements. Thus the equivalent of lime is 28,

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127. In fixing combining numbers, why is the hydrogen scale generally adopted? What are the advantages of the oxygen scale? 128. What is meant by multiple proportions? Example. 129. How does the law of equivalents affect

as it is a compound of calcium 20, and oxygen 8 (20+8=28); for carbonic acid 22; carbon 6, oxygen 16 (6+16=22); and of marble or chalk, it is 50; lime 28, carbonic acid 22 (28+22=50). A knowledge of the combining numbers is of the first importance in all departments of practical chemistry, whether in the laboratory, or in the manufactory, to determine the quantities in which materials shall be employed. The combining numbers of the substances upon the Chart should be committed to memory.

**130. Combination by Volume.**—In dealing with gas, it is more convenient to measure than to weigh it; and as it combines by equivalents in weight, it becomes important to know what amount of volume they occupy. When we take equivalent quantities of the gases, we find that the spaces they fill do not bear the same relation to each other as the equivalent weights, nor are the spaces all alike, yet a very simple relation does subsist between them, which is shown as follows: The equivalent number being 8 for oxygen, 8 grains of it are placed in a vessel which will exactly contain them. The gas is then removed, and 32 grains of solid phosphorus introduced, that number being the equivalent of this element. The phosphorus is then vaporized by heat, and the vapor exactly fills the vessel. The equivalent weights of oxygen and phosphorus are unequal; but when brought into the same condition of vapor, they fill equal spaces, and have, therefore, equivalent volumes, which are expressed thus: oxygen = □, phosphorus = □.

**131.** If, now, we take an equivalent of hydrogen, or 1 grain, we find that the vessel will hold but half of it; its volume is therefore □□, being double that of the oxygen or phosphorus. Consequently, if we wished to unite oxygen and hydrogen in equivalent weights, so as to form water, we would take one measure of the former, and two of the latter. Sometimes gases are condensed by combination. Two measures of hydrogen and one of oxygen produce but two of watery vapor. Thus oxygen = □, hydrogen = □□, steam = □□. In measuring by volume, oxygen has hitherto been taken as the unit, but Gerhardt makes hydrogen the unit. His views will be better understood after studying the nomenclature.

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compound bodies? How are their equivalents determined? Example. Why is a knowledge of combining numbers important? 130. How is the combining proportion of gases estimated? How are combining volumes ascertained?

## § III. *The Atomic Theory.*

**132.** The laws of chemical combination which have been explained are independent of all speculation, being the result of facts established by multiplied observations and experiments, and may be verified at any time by accurately analyzing a few chemical compounds. But this was unsatisfactory—an explanation was demanded—a reason was required for the remarkable behavior of chemical force in thus rigidly limiting the proportions of combining quantities. To solve this problem, Dr. Dalton offered the *Atomic Theory*, which has already been referred to in its physical aspects.

**133. What it Teaches.**—This theory assumes, *first*, that all matter is composed of indivisible, unchangeable atoms; *second*, that atoms of the same element have the same weight, but that in different elements they have different weights; *third*, that the combining numbers represent these relative weights; and, *fourth*, that all chemical compounds are formed by the union of different atoms.

**134.** This doctrine, if accepted, offers an explanation of the laws of combining proportions. Thus, if water be composed of an oxygen atom weighing 8, and a hydrogen atom weighing 1, then its composition must be definite and invariable, and every specimen of it, whether it be a grain or a ton, must give, upon analysis, $\frac{8}{9}$ of one gas and $\frac{1}{9}$ of the other. Also, if the atoms of each element possess invariable weight, they must, in all their combinations, exhibit equal and reciprocal values. And again, as an atom is the least quantity that can enter into combination, the compound can only be increased by the addition of *whole atoms*, so that the combining number expressing the large quantity must be an exact multiple of the *single* atomic number. The *Chemical Chart* offers a beautiful illustration of the atomic theory.

**135.** Whether matter be infinitely divisible or not, is an old controversy, not yet settled. It would *seem* that it is so, as we cannot imagine a particle so minute that we may not conceive it to be again divided. But putting aside speculation as to what *may be*, the chemist assumes that in the present order of nature there *are*

131. How is it in the case of water? 132. How have the laws of combination been determined? Why was the atomic theory proposed? 133. What is its first assumption? Its second? Third? Fourth? 134. What is said of this theory if ac-

ultimate indivisible atoms. The atomic theory has been objected to as not in accordance with all the facts of chemistry; yet as a convenient hypothesis to facilitate study and inquiry, it has been, and is still of incalculable value. We subjoin two cases of its most recent application.

**136. Isomerism.**—Until lately, it was the prevailing opinion that chemical properties depend solely upon chemical composition, and hence that similar composition necessitates similar properties. For a long time, if two substances of different properties were found, upon analysis, to have one composition, it was held that the experimenter must have erred. But so constant and increasing were such results as at length to establish the fact that bodies of the same composition may still have different properties. Bodies thus constituted are said to be *isomeric*, from *isos*, equal, and *meros*, measure, and are called *isomerides*. For example, the fragrant oil of roses and the chief illuminating constituent of common street gas are isomeric; a compound atom of each consists of four atoms of carbon and four of hydrogen. To explain this we are compelled to assume that the constituent atoms of a compound may have different *arrangements*. The same atoms which if grouped in one way give rise to one substance, if regrouped in another give rise to a different substance.

**137.** If bodies have the same *absolute* composition, as in the above example, they are said to be *metameric* compounds, and the groupings of their constituent atoms may be represented by the structure of such words as *ate*, *eat*, *tea*, &c. But sometimes substances have only the same *proportional* composition; they are then said to be *polymeric* compounds. Thus aldehyde consists of carbon, four; oxygen, four; and hydrogen, two; while acetic ether consists of just double these elements; yet the per cent. proportion of both these compounds is the same. The relations of such bodies resemble those of the words *Pa*, *Papa; Tar*, *Tartar*.

**138. Allotropism.**—Something analagous to this is manifested by the elements themselves. Within the last few years it has been found that the elements may change their properties and

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cepted? 135. What does the chemist assume concerning atoms? How is the atomic theory estimated? 136. What views have been held concerning the properties and composition of bodies? What has been recently discovered? What is isomerism? Example? Explanation? 137. What is metamerism? Polymerism? 138. What is said of the different states of the same elements? Example. What

pass from state to state. We have a striking instance of this in carbon, which in one condition gives us the brilliant, transparent, and almost incombustible diamond; in another, the black, opaque, easily inflammable charcoal; while in another we have the metal-like graphite. This curious phenomenon is called *allotropism*, a word which means simply *different states*. It was at first supposed that but few of the elements were allotropic, but it is now found that nearly all of them take on this doubleness of condition, while some have several phases. The explanation of these effects is that the atoms constituting the element are differently arranged in the different cases.

## § IV. *The Nomenclature—Chemical Language.*

**139.** The chemical nomenclature is a system of naming in which the structure of the terms employed expresses the composition of the substances to which they are applied. The beautiful order of chemical composition is well fitted for such a device, and hence this nomenclature is the most perfect to be found in any of the sciences. It was devised by a committee of the French Academy in 1787, as it was found that chemical compounds were multiplying so rapidly that no memory could retain their arbitrary names. With the progress of the science the principles of the nomenclature have been changed and extended.

**140. Naming the elements.**—In the case of elements long known, the old established names were retained, but where a new one was discovered, a name was given expressive of some leading quality by which it was distinguished. Thus chlorine takes its name from its greenish color; iodine from its purple vapor; phosphorus (*bearer of light*) from its being luminous in the dark. The lately discovered metals are distinguished by the common termination *um*, as platinum, thalium. Among non-metallic elements, analogy of properties is indicated by similarity of termination, as chlorine, bromine, fluorine; or carbon, boron, silicon.

**141. Naming of binary compounds.**—The union of two elements forms a *binary* compound (*bis*, twice), three elements form

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term is applied to it? 139. What is the chemical nomenclature? What is said of it? When and by whom was it devised? For what reason? What has changed it? 140. What rule has been observed in naming the elements? How are the metals distinguished? How is analogy of properties indicated in other elements?

a *ternary*, and four a *quaternary* compound. Where the compound contains but one atom of each, both elements are designated in the name. Thus a compound of oxygen and lead is called *oxide of lead.* When binary compounds are decomposed by the electrical battery, one element passes to the positive pole, and is termed the *electro-negative* element; the other goes to the negative pole, and is called the *electro-positive* element. In forming a name, *the electro-negative ingredient is placed first*, and marks the genus, while the electro-positive comes last, and indicates the species. The first, or electro-negative element, is distinguished by the termination *ide;* thus oxygen forms oxides; chlorine, chlorides; iodine, iodides; fluorine, fluorides; carbon, carbides; sulphur, sulphides; phosphorus, phosphides. The suffix *uret* was formerly applied in these cases, as sulphuret of lead, carburet of iron, but it is now less used.

**142. Acids.**—Acids form an extensive and important group of binary compounds. They are generally soluble in water, sour to the taste, and change vegetable blue colors to red. *Litmus*, a blue vegetable extract, is commonly used as a test of acidity. When not weakened by dilution with water, they decompose and destroy vegetable and animal substances, and likewise corrode and dissolve the metals. Acetic, sulphuric, and nitric acids are familiar examples of this class. Acids are also distinguished by their powerful attraction for another class of bodies called *bases.* This is, indeed, their genuine test, for certain insoluble substances, as silica, neither taste sour nor affect blue paper, yet, when melted, they manifest acid properties, combining strongly with bases. The principle acids are of two kinds, called *oxacids* and *hydracids.* The former are so named because oxygen is their leading ingredient; whereas, in the latter, it is hydrogen.

**143. Naming the acids.**—Oxacids are named from the element with which the oxygen unites. Thus sulphur with oxygen gives sulphuric acid; carbon with oxygen gives carbonic acid. The varying proportions of oxygen are distinguished by terminations and prefixes. Thus, *ic* indicates the stronger, *ous* a weaker, and

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141. How is the number of elements in a compound denoted? When there is but one atom of each element in a binary compound, how is it named? Which comes first? What termination has it? Examples. 142. What are acids? What is litmus? What is the distinguishing test of acidity? How are the principal acids divided? 143. How are oxacids named? How are the different proportions of

the prefix *hypo*, which signifies *under*, a still weaker acid. Thus, nitric acid contains more oxygen than nitrous acid, and this more than hyponitrous acid. The prefix *hyper* means *more*, as hyperchloric acid, or more commonly perchloric acid, which contains more oxygen than chloric acid. In naming the hydracids, both elements are mentioned; as hydrogen and chlorine form hydrochloric, or, according to the principle just laid down, chlorohydric acid; iodine and hydrogen iodohydric acid.

**144. Bases.**—All bodies which combine with acids and neutralize them are called *bases*. This class includes alkalies, alkaline earths, and many other substances wholly unlike them in character. Alkalies, in their leading properties, are the reverse of acids. They have an acrid, nauseous taste, and restore the vegetable blue colors turned red by acids. Like acids, however, they are powerfully solvent and corrosive. Potash, soda, and ammonia are examples. Alkaline earths, as lime and magnesia, possess these qualities in a lower degree.

**145. Naming the Bases.**—Most of the bases are formed by the union of oxygen with metals, as oxide of iron, oxide of potassium. When oxygen combines with the same element in different proportions, forming several oxides, the degree of oxidation is indicated by the use of prefixes. Thus, *proto* means one equivalent, or the lowest proportion of oxygen; *deuto*, two; and *trito*, three. *Per* denotes the highest degree of oxidation, and is often applied to the deutoxide and tritoxide. *Bin*-oxide is equivalent to deutoxide, and *ter*-oxide to tritoxide, while *sesqui*-oxides are those in which the oxygen is in the proportion of one and a half to one of the element with which it is combined. Some oxides of inferior basic properties are termed *sub*-oxides.

**146. Salts.**—The combination of an acid and a base forms a *salt*. The properties of both constituents are neutralized, and the resultant compound has entirely new qualities. The neutralization may be perfect or partial; if perfect, a *neutral* salt is the result. If, however, there is not sufficient base completely to saturate the acid, an *acid salt*, or *super-salt*, is formed; while, if the base is in excess, a *basic salt*, or *sub-salt*, results. The term salt is not limited

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oxygen denoted? How are the hydracids named? 144. What are bases? What are included in the class? What are alkalies? Alkaline earths? 145. How is the proportion of oxygen in a base expressed? 146. What are salts? Neutral salts? Acid? Basic? What is said of the saline taste? 147. How are the salts

to bodies having a saline taste. Many tasteless substances, such as glass, marble, and various minerals and rocks, being composed of acids and bases, are properly salts. The constitution of salts will be noticed hereafter.

**147. Naming the Salts.**—Salts are named from both their elements, as phosphate of lime from phosphoric acid and lime. But as several acids of the same general name may combine with one base, the salts formed are distinguished by turning the *ic* of the acid into *ate* of the salt; and *ous* of the acid into *ite* of the salt. Thus, nitric acid forms nitr*ates*, phosphoric acid, phosph*ates*, &c., while nitrous acid produces nitr*ites*, and hyposulphurous acid, hyposulph*ites*. The basic element of a salt is indicated by its usual prefixes; thus, *proto*sulphate of iron is sulphate of the *proto*xide of iron. Salts of the protoxide are called *proto*salts, and salts of the peroxide, *per*salts. Illustrated exercises in the nomenclature of acids, bases, and salts, will be found upon the Chemical Chart.

**148. Symbols.**—To facilitate chemical labor, Berzelius introduced a system of *symbols*, by which, not only the names of substances, but their composition and changes are expressed by abbreviations. The symbols of the elements are the first letters of their names, as, for carbon C, for oxygen O, for hydrogen H, and for nitrogen N. But, as several substances may have the same initial letter, we either employ, to distinguish them, the first letter of their Latin names, or add a second small letter. Thus, as C stands for carbon, Cl is taken for chlorine; and as P represents phosphorus, we use, for potassium, K, from *kalium*, the Latin for potash. A symbolic letter denotes, not merely an element, but one proportion, or atom, of that element. Thus, H stands for one equivalent of hydrogen, and O for one equivalent of oxygen. If more proportions than one are to be expressed, a small figure is added: thus, $O_2$ stands for two proportions of oxygen, $H_3$ for three of hydrogen. In the table of elementary bodies (111) the symbol and combining number are given opposite each name.

**149. Formulæ.**—To express composition we place together the symbols of the elements of which the compound is formed; thus HO is the symbol for water, $CO_2$ for carbonic acid. Here the

named? What does *ate* signify? *ite*? Examples. How is the basic element indicated? 148. What are symbols? How are the symbols for the elements obtained? What does the symbol denote? How is more than one equivalent expressed?

*electro-positive* element is placed first. A collection of symbols expressing composition or changes is called a *formula*. In expressing changes the sign + signifies addition to or mixture with, while the sign = signifies equivalency with or conversion into. The substances which act upon each other to produce chemical changes are called *reagents*, and the changes themselves *reactions*. The results of reaction are expressed by means of chemical *equations*, in which the substances before the change are placed at the left, and the products of the change at the right. The reaction between nitrate of baryta and sulphate of potash is thus expressed:

$$\overbrace{KO, SO_3}^{\text{Sulph. of potash.}} + \overbrace{BaO, NO_5}^{\text{Nit. of baryta.}} = \overbrace{BaO, SO_3}^{\text{Sulph. of baryta.}} + \overbrace{KO, NO_5}^{\text{Nit. of potash.}}$$

As nothing is either gained or destroyed in the operation, the quantities on each side are equal, as may be tested by forming an equation of the equivalent numbers.

**150.** A bare statement of the elements of a compound, with no indication of the *way* in which they are combined, is called an *empirical* formula (28). *Rational* formulæ express the views of the chemist as to the manner in which the elements are grouped. Thus the empirical formula for nitrate of potash would be $KNO_6$. But as it is formed by the combination of nitric acid and potash, it is rationally written as if it consisted of them; thus $KO,NO_5$, the comma serving, as it were, to dissect the compound, and show how it is constituted. Sometimes the plus sign is used to indicate feeble attraction. Thus crystallized carbonate of soda is $NaO, CO_2+10HO$, the ten equivalents of water being more loosely associated with the salt than the ingredients of the salt are with each other. To denote more than one equivalent of a compound, its formula is inclosed in a bracket with the number prefixed. Thus, three equivalents of nitrate of potash would be written $3(KO,NO_5)$. The figure prefixed multiplies only the symbols in the brackets, as in the following formula for crystallized alum, which contains 3 equivalents of sulphuric acid:

$$Al_2\ O_3\ 3(SO_3)+KO,\ SO_3+24HO.$$

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149. What are formulæ? How are the symbols arranged? What does + signify? What is meant by the sign =? What are *reagents* and *reactions*? How are the results of reaction represented? 150. What are empirical formulæ? Rational formulæ? Give an illustration. What does the plus sign sometimes denote? How is more than one equivalent of a compound expressed? If brackets are omitted?

If brackets are omitted, the figures multiply all between them and the next comma or plus sign.

**151. Later views of Gerhardt and Laurent.**—Certain ideas advanced by these chemists have been latterly growing in favor. Hydrogen, being the lightest substance known, is taken as the standard for the specific gravity of gases. It is found that the bulk or volume of a grain of hydrogen is the same as that of 14 grs. of nitrogen, 35.5 grs. of chlorine, and 80 grs. of bromine. Now these numbers are precisely the atomic weights of the bodies, so that the same numbers express both atomic weight and specific gravity. But the same bulk of oxygen weighs 16 grs., which is just twice its atomic number. And when the vapor volumes of carbon and sulphur are determined, it is found that to fill the same space takes 12 grs. of carbon and 32 of sulphur; these again being just twice their atomic weights. To obtain uniformity therefore, as well as for other reasons which cannot be here stated, the atomic numbers of oxygen, carbon, and sulphur are doubled. In this way the same numbers are made to express three facts, viz.: atomic weight, specific gravity, and combining volume.

**152.** On this view the symbols represent *equal volumes* of their elements. Hence the formula for chlorohydric acid, HCl, implies a combination of one volume of hydrogen with one of chlorine [H Cl]. Water is a combination of two volumes of hydrogen with one of oxygen, thus [H H O], and is written $H_2O$; while ammonia, $H_3N$, implies a union of three volumes of hydrogen with one of nitrogen [H H H N]. It will be noticed in the case of water that the doubling of oxygen is the consequence of halving the hydrogen; if we take *equal volumes*, their weights are as 16 to 1; but as there are two volumes of hydrogen, the composition of water becomes $H_2O$, the oxygen being 16. There are other reasons for considering the composition of water as more complex than has been formerly supposed, so that without adopting the views of Gerhardt, we may still regard water as $H_2O_2$ instead of HO.

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151. What place does hydrogen hold in the system of Gerhardt? What relations have been found to exist among some of the elements? Why are the numbers for carbon, sulphur, and oxygen doubled? What is thus gained? 152. On this view what do the symbols represent? What does H C l imply? How is water written? Ammo-

# CHAPTER III.

## ELECTRICITY.

### § I. *General Considerations.*

**153.** The true idea of force is difficult to fix steadily in the mind; in the early stages of science it seemed impossible. (388) Forces were therefore *materialized*. It was said there are two kinds of matter, the gross sort which we can weigh, and the other which we cannot weigh—*imponderable* matter consisting of subtile fluids or particles which by their assumed properties produce the effect of force. Hence the forces heat, light, and electricity are known as *imponderables*. These crude conceptions of force may have been useful and necessary in the earlier progress of science, but they now no longer answer. The idea of a multiplicity of fluids of different natures is out of harmony with the whole body of recent facts, and has become a positive hindrance to the advance of thought. All the tendencies of inquiry are toward a far closer relation than was formerly suspected between the different modes of force—a great and fruitful idea which might perhaps have been worked out earlier but for the notion that each force is a peculiar and distinct kind of matter. As we know nothing of force except through matter and by changes in it, the later views regard it as only an activity, or mode of motion, of common matter.

**154.** We take up electricity before heat and light, because it is best adapted to familiarize the pupil with the general conception of *polarity*, which has become a fundamental idea in the newer philosophy of forces. For the same reason magnetism is the branch of electricity first considered. It is also desirable to study electricity first, as it has furnished the most delicate and valuable instruments for investigations in heat.

**155. Origin of the Science.**—Nearly 2,500 years ago it was observed that when a piece of amber was rubbed, light substances near by became animated with motion, and flew toward it. This was considered marvellous, and amber was thought to have a soul.

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nia? What is said in regard to water? 153. Why were forces at first materialized? How was matter divided? What is said of this conception? What is the present tendency? 154. Why is electricity considered first? 155. State its origin? 156.

Long afterward it was found that other substances manifested the same property; they were, therefore, amber-like, and the peculiar agency received the name of *electricity*, from the Greek word *electron*, amber.

**156. Its present Importance.**—For more than two thousand years nothing was done to unfold this principle, and yet the blank ignorance of that long period is perhaps less astonishing than the magical developments of the last century. Electricity has been demonstrated as the cause of the grandest phenomena of the atmosphere, and the most extensive changes in the earth. It has given to chemistry new and powerful resources of analysis and synthesis; it has added to its elements, multiplied its compounds, and revolutionized its theory. It has given to the physiologist a deeper insight into the forces of life, and to the physician a new method of combating disease. It copies pictures, moulds metals, separates ores, explodes the blasting charge in the earth and sea, and, as if to crown its brief and splendid career with a new endowment of civilization, it has literally broken down the barriers of space and time, and in the telegraph has conferred upon man an earthly omnipresence.

**157.** It is now established that electricity is most intimately connected with heat, light, and the chemical and molecular forces. We can detect its presence, either as cause or effect, in almost every action and change around us; and because of this close and varied relation to the other powers, as well as its essential interest, it deserves the earnest attention of the scientific student.

## § II. *Magnetic Electricity—Magnetism.*

**158.** The natural magnet is an iron ore which has the remarkable property of attracting to itself particles of iron or steel. If suspended, it takes a north and south direction, and from this pointing or *leading* property it is called the *lead-stone*, or *loadstone*. It derives its name *magnet* from the circumstance of its having been first discovered in the province of Magnesia in Asia Minor.

**159. Artificial Magnets.**—If a steel bar be rubbed by a natural

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What is said of its present importance? 157. Why should it be carefully studied? 158. What is the natural magnet? Whence are its names derived? 159. Describe an artificial magnet? What are its poles? What is the mariner's compass? 160. How may the attraction and repulsion of magnetic poles be mani-

Fig. 47.

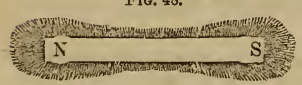
Magnetic needle.

magnet, it acquires magnetic properties, and becomes an *artificial* magnet. If properly shaped and poised upon a pivot, Fig. 47, it takes a northerly and southerly direction. The extremity which points northward is called the north pole of the magnet, and that which turns southward, the south pole. A magnetized steel needle properly suspended and attached to a card marked with the cardinal points, constitutes the mariner's compass.

**160.** If a second needle be brought near the first, it will be noticed that they exert a powerful influence over each other. The north pole of each attracts the south pole of the other, while north pole repels north pole, and south pole repels south pole. In short, *like poles repel, and unlike attract each other*. These influences are exerted through all kinds of matter; glass, wood, metals, or the human body.

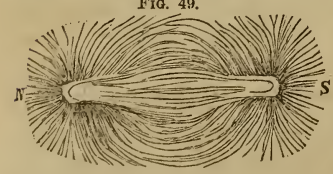
**161. Distribution of the force.**—The magnetic force is manifested chiefly at the poles, as may be seen by rolling a magnetic bar in iron filings; they accumulate mostly at the extremities, the central point being neutral, Fig. 48. If a sheet of paper be laid upon the bar, and iron filings be dusted over it, on gently tapping the paper, they gather thickly around the poles, extending away in curved lines, called *magnetic curves*, Fig. 49. Thus the two magnetic forces are always produced simultaneously; are equal in amount, but opposite in direction, and as these opposite powers are manifested in the poles of the magnet, they are called *polar forces*.

Fig. 48.




Magnet in iron filings.

Fig. 49.




Magnetic curves.

**162. Magnetic Induction.**—The preceding experiments show that the magnet has the power of raising up magnetism in ad-

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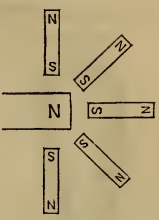
fested? 161. What is shown by Fig. 48? How are magnetic curves produced? What is shown by this experiment? 162. Explain what is meant by magnetic induction? How do Figs. 50 and 51 illustrate this? 163. What is the result of breaking a magnet? How do magnetized particles act? What

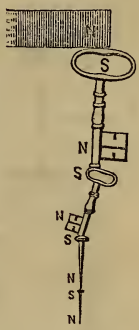
joining bodies;—in fact, each of the little particles of iron becomes a magnet with a north and south pole. This may be proved by placing several bars of soft iron around the pole of a magnetic bar, Fig. 50, when they all become temporarily magnetic. The permanent magnet *induces* the influence in the adjacent bars, which are hence said to be magnetized by *induction*. A key may be supported by a magnet, Fig. 51, and this will hold a second smaller key, this a nail, and the nail a tack, the whole receiving its magnetism by induction from the bar, and each possessing its separate north and south polarity.

Fig. 50.




Magnetic induction.

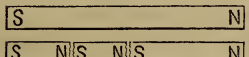
Fig. 51.




Magnetic chain.

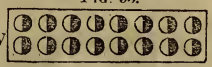
**163. Polarity of particles.**—Now the particles of the magnet are in the same condition as the magnet itself. If a magnet is broken, as in Fig. 52, and the pieces are broken again and again, the smallest particles still have opposite poles. But as a magnet induces its own state in a piece of soft iron near it, so each particle induces a polar condition in the adjoining particle; that in the next, and thus the effect is propagated throughout the magnet. As each particle thus acquires polarity, and acts by induction upon all the others, the opposite powers become accumulated at the opposite extremities of the bar. This is illustrated in Fig. 53, where the atoms are represented by circles, the shaded sides representing south polarity, and the unshaded their north polarity. It may be observed that while steel *retains* its magnetism—that is, its particles remain fixed in their polar relation, soft iron, on the contrary, only remains a magnet while immediately acted upon; its particles forced into the polar state by induction, resume their neutral relation when the coercing power is withdrawn.

Fig. 52.




A broken magnet.

Fig. 53.




Polarity of particles.

**164.** The earth is a vast magnet, varying in intensity at different times and places, which produces variations of the needle. A remark-

is the effect? What does Fig. 53 illustrate? 164. What is the effect of the variation in the intensity of the earth's magnetism upon the needle? What of the solar spots?

able correspondence has been observed between certain of these fluctuations and changes in the number and magnitude of the solar spots.

FIG. 54.

Horse-shoe magnet.

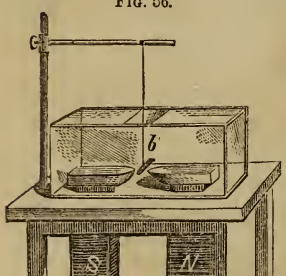
**165. The horse-shoe magnet.**—Magnetic bars are usually bent in the shape of a horse-shoe, so that the poles are brought near together, as in Fig. 54. They are then connected by a piece of iron called the *armature*, which adheres to the poles with a force depending upon the power of the magnet. In Fig. 55 we see the two poles of a horse-shoe magnet as if looking down upon them. The space included within the circle is called the *magnetic field;* the continuous line joining the poles represents its *axis*, and the dotted line its *equator*. All substances which, when freely suspended between the poles of a magnet, arrange themselves axially, are classed as magnetic. They are but few, iron, nickel, cobalt, and oxygen being the most important.

FIG. 55.

Magnetic field.

**166. Diamagnetism.**—Certain bodies, when suspended in the magnetic field, assume an equatorial direction, as if repelled by the poles. The force thus manifested is so feeble that in experimenting, the objects are screened from currents of air by a glass case, Fig. 56, in which *b* represents a bar of bismuth suspended by fibres of unspun silk between the two poles of a magnet. This property of bodies was lately discovered by Faraday, and named by him *diamagnetism*, while he terms common magnetism *paramagnetism*. Bismuth and antimony show it in the most marked degree, but it is also manifested by wood, leather, water, &c.; in fact, all substances not magnetic are now regarded as diamagnetic. It was long thought that magnetism was a rare property, but it now appears that all matter is affected, one way or another, by magnetism.

FIG. 56.

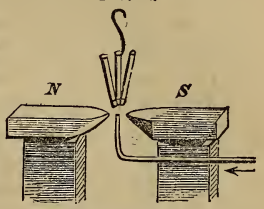



Diamagnetism.

165. What is the horse-shoe magnet? Explain Fig. 55. When are substances said to be magnetic? 166. Do all bodies place themselves axially in the magnetic field?

**167.** Oxygen is magnetic, but many other gases are diamagnetic. Faraday proved this in the following beautiful manner: A bent tube, Fig. 57, conveyed the gas for experiment into the centre of the magnetic field. Three short glass tubes open at both ends were suspended with their lower openings arranged in the equatorial line, with the middle tube just above the bent tube. So long as there is no magnetic action, the gas flows directly up the middle tube, but the moment the magnet is brought into play, the diamagnetic gases are diverted into the side tubes. The course of the current is shown by placing a piece of paper moistened with ammonia in the lower tube, and other slips moistened with chlorohydric acid in the upper ones, the white fumes showing the direction of the current. Gases heavier than air flow downward, and for testing these the arrangement was reversed. A flame placed in the magnetic field is widened out equatorially.

Fig. 57.




Diamagnetism of gases.

## § III. *Franklinic Electricity—Electro-Statics.*

**168.** The kind of electricity to be now noticed is called *static electricity*, from its being in a state of stagnation or rest.* It is also distinguished as *Franklinic* electricity from Dr. FRANKLIN, who was one of the most celebrated investigators of this branch of the science.

**169. Electrical excitation.**—If a dry, warm glass tube be rubbed with a silk handkerchief, several effects are produced by the friction. A feeble, crackling noise is heard; there is a peculiar odor and a marked sensation when the tube is held near the hand or face, and if it be dark, faint, luminous flashes will appear to dart from the surface of the glass. If the tube be now presented

* The word *statics* is derived from a Greek term signifying *to stand*, and is applied to forces in a state of rest or equilibrium. Thus *hydrostatics* treats of the pressure and properties of water in a state of rest; and *electrostatics* of electricity in a stagnant or motionless condition. *Dynamics*, on the contrary, is derived from a Greek word signifying *power*, and indicates the science of matter in motion, or forces in action. Thus *hydrodynamics* considers the properties of falling or flowing water, and *electrodynamics* of electricity in a state of motion, as currents.

What are FARADAY'S discoveries in this connection? How may all bodies be classed? 167. How did FARADAY determine the magnetic relations of gases? What was the effect upon flame? 168. What is static electricity? Why is it also called Franklinic? 169. What are the effects of friction upon a dry, warm glass tube? What are elec-

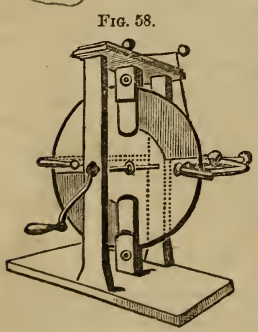
to any light substances, as bits of paper or feathers, they are attracted to the glass. Bodies in which this quality has been aroused are said to be electrically excited or *electrified*, and are termed *electrics*. They are numerous, including all resinous, gummy, and glassy substances, hair, silk, dry gases, and air.

**170.** Some bodies, as the metals, water, charcoal, &c., allow electricity to pass readily through them, and are hence called *conductors*. Other substances, such as glass, resins, wool, do not readily allow its passage, and are termed *non-conductors*. As the latter tend to arrest or confine electricity, they are called *insulators*. Yet this simple division of bodies into conductors and non-conductors is hardly true to nature, for there is really no substance which perfectly conducts, or perfectly obstructs electricity. They differ only in degree.

**171. Electricity of the earth and air.**—Our globe is a conductor of electricity, and is termed the *common reservoir*. If an excited body is connected with the earth by a conductor, the electricity escapes into the ground. Air is a non-conductor; and, pervading all bodies, it acts as a universal insulator. All electrical manifestations around us depend upon this, for if air were a good conductor, no body could preserve its electricity. Yet moisture conducts, so that the air, when charged with dampness, carries off electricity quite rapidly. For successful experiments, therefore, the air should be dry.

**172.** The *Electrical machine* consists of a glass cylinder or plate, Fig. 58, pressed by rubbers, and turned by a crank, so as conveniently to produce a large amount of friction. Brass balls and rods are used to collect and carry away the electricity. The *Leyden Jar* is simply a glass jar covered inside and out with tinfoil as high as the line shown in Fig. 59. A metallic ball connects with the interior coating, the outer being in communication with the earth. If the ball is brought near the conductor of an electrical machine, it receives a succession of sparks, and be-

Fig. 58.



Electrical machine.

trics? Mention some. 170. What are conductors? Non-conductors? Insulators? Is this division strictly true? 171. What is the earth electrically? Is the air like the earth in this respect? What if it were? What is the effect of moisture?

comes *charged*. Then, on connecting the inner and outer coats by a conductor, discharge takes place, with a brilliant spark, and equilibrium is restored. The jar serves to accumulate electricity, and a connected series of such jars forms the *Leyden Battery*.

Fig. 59.

Leyden jar.

**173. Two kinds of electricity.**—If a ball made of pith of elder be suspended by a silken thread and brought near an excited glass tube, it will be first attracted to it, and then repelled from it. If another suspended pith ball be brought near a stick of excited sealing wax, it will act in the same manner. Both balls are excited and both repelled. If the differently excited balls are now brought near each other, they are attracted together, whereas if both had been excited by the glass alone or by the wax alone, they would have repelled each other. There are thus two kinds of electricity; that from glass is called *vitreous*, and that from wax *resinous*. Each is self-repulsive, but bodies excited both ways attract each other; or, as it is commonly expressed, *like electricities repel, and unlike attract*—the same principle that we have just seen in magnetism.

**174. Electroscope.**—The property of self-repulsion is employed to test the presence and intensity of electrical excitement. A simple electroscope is formed by suspending two pith balls by linen threads, as in Fig. 60. If touched by an excited body, they are repelled, Fig. 61, and the degree of divergence is a rough measure of the force awakened.

Fig. 60.

Unexcited pith balls.

Fig. 61.

Excited pith balls.

**175.** On the same principle, slips of gold leaf attached to a conducting rod in a glass jar, Fig. 62, form a very delicate electrometer. Such is the sensibility of the instrument that a slight flap of a silk handkerchief on the plate at top renders the leaves divergent. We thus become aware how trifling are the causes that disturb the electric equilibrium of the objects around us. Not the smallest change in place or condition can

172. What is the electrical machine? Describe the Leyden jar. How is it charged and discharged? What is a Leyden battery? 173. How may it be shown that there are two kinds of electricity? What are they called? How do they affect each other? 174. Explain the electroscope, Fig. 60. 175. What does Fig. 62 represent?

Fig. 62.

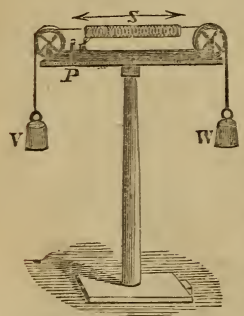
Gold-leaf electroscope.

occur without interfering with this mysterious agency, although the balance is so quickly adjusted that we are not aware of the disturbance. 'In cutting a slice of meat, there may pass between the steel knife and silver fork enough electricity to move the needle of a telegraph.' (C.V.Walker.)

176. **Electric Tension.**—The electrical excitement of a body may rise so high as to overcome the resistance which confines it and escape, rending a passage through the air, when all excitement disappears. A body electrically excited is said to be *charged;* the restoration of equilibrium is called *discharge*, and is seen in the electric spark and the flash of lightning. The degree of excitement or intensity of the charge is called *electrical tension*, and may be compared to the pressure of steam, or the bending of a bow or spring; its discharge to their release.

177. This analogy of the spring may be carried much farther.

Fig. 63.




Duality and polarity of mechanical forces.

It is a principle of nature that forces develop themselves in a double or opposite way. We see this in mechanics in the elasticity of a spiral spring, Fig. 63. When unstretched it manifests no force. Nor can it be stretched from one end alone. If hooked to the pin P, and the weight W is attached, it will seem to be stretched by one end only. But this is a mistake; for by substituting the weight V for the pin P, the strain upon the spring is the same; as the arrow indicates, the forces are double, equal, and opposite.

178. The same principle is observed in electricity. It is a double force manifesting itself by actions and reactions which are equal and opposite. One kind of electricity cannot be produced unless it is accompanied by the other. Whenever vitreous electricity is developed, a corresponding amount of resinous electricity

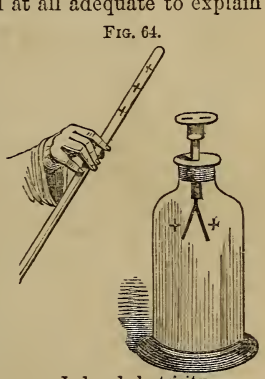
Give instances of its sensibility. What does this show us? 176. Explain what is meant by electric tension. To what may it be compared? 177. In what manner are forces developed? How may this be shown? 178. How is it in electricity?

invariably accompanies it. It may not be at first perceptible, but will be recognized upon careful examination. Electricity is thus, like magnetism, a *polar force.*

**179. Electrical hypothesis.**—Electricity has generally been regarded as a subtile material fluid pervading all matter. Some hold that the two electricities are two fluids which are mutually attractive, though each is self-repellant. FRANKLIN simplified the matter by regarding electricity as analogous to heat, and, as all the effects of heat and cold were explained by the excess or deficiency of a single fluid, caloric, he proposed to explain electrical effects by variations in quantity of a single electric fluid. He maintained that bodies vitreously electrified have an excess of it above their natural share, which excess he called the *positive* state, while bodies resinously electrified are deficient in the fluid, or in a *negative* condition. The positive electrical state he distinguished by the plus sign (+), and the negative by the minus sign (−). When both are used together, they signify neutralization, or no excitement.

**180.** The Franklinic terms and symbols are still used, but we must guard against their misguiding influence. Positive electricity is no more positive, real, or powerful than negative, and the terms might be reversed so far as the character of the electricities is concerned. Nor is the idea of a fluid at all adequate to explain the facts. Prof. MILLER remarks: 'The supposition of an electric fluid is gradually being abandoned. The supposition of a gravitative fluid might with nearly as much propriety be insisted on to explain the phenomena of gravitation, or a cohesive fluid to account for those of cohesion.'

FIG. 64.



Induced electricity.

**181. Electrical Induction.**—Electrical bodies, like magnetic, act at a distance to disturb the equilibrium of neighboring bodies. If an excited glass rod be brought near an electroscope, though there be no contact, the leaves will diverge, Fig. 64, and upon examination it will be found that the

179. How has electricity been generally regarded? What was Franklin's explanation? What do the signs plus and minus signify? 180. In the use of these terms what are we to guard against? How is the conception of electricity as a fluid now

cap is negatively electrified, and the leaves positively. The approach of the excited tube decomposes their natural electricity, the negative element being attracted, and the positive repelled. This action of an excited body, without discharge, through a medium upon distant bodies, is known as *electrical induction.*

**182.** Induction is a kind of preparation for discharge. When electricity is about to move, or discharge to occur, the whole course through which it will pass is, as it were, *felt out beforehand;* at first and infallibly the line of least resistance is found and pursued. If two conductors are before it, it takes the easiest course at the outset.

FIG. 65.

Path of the discharge.

**183.** Fig. 65 represents fragments of gold leaves casually laid upon paper, and producing with the paper a series of bad and good conductors. A discharge finds its path across the interrupted circuit from P to N, burning up the leaves and parts of leaves, as shown by the shaded track. These remarkable results are necessary consequences of the principle of induction. The charged body induces attractions in all directions, and the discharge will of course be determined through that range of materials which from their nature and position are most excited; which present the strongest attractions, and, of course, the least obstruction.

**184. Theory of Induction.**—As there are all degrees of conduction and insulation, Dr. FARADAY holds that we must look upon *conduction* and *induction* as only different degrees of the same mode of movement; in all cases, it is an effect communicated from atoms to atoms. If, when a body is electrified, its particles discharge instantaneously into each other, *conduction* is the consequence. If the particles do not readily discharge, but hinder the course of the electricity, they are immediately forced into positions of constraint: they become *polarized*, and as each particle induces a state of polar tension in its neighbor, the effect is transferred to a

regarded? What is it thought to be? 181. What is the effect of an excited glass tube brought near an electroscope? What is induction said to be? 182. When electricity is about to move, what course does it take? 183. Explain Fig. 65. Why is this? 184. Describe FARADAY'S theory of induction. Explain Fig. 66. On

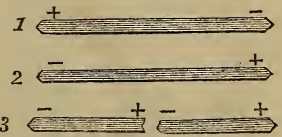
distance. In Fig. 66, P represents a positively charged body, and *a b c d* intermediate particles of air. These are thrown into opposite states or polarized, as is represented by the white and black sides of the spheres, and thus the effect is propagated to the body N, which is electrically excited. We have said that insulators arrest electricity, but on this view they only stop movement by conduction; they transmit it by *induction* through the polarization of their particles. As the polar particles are in active relations of force to those around, it is obvious the effects may be propagated in various directions. Hence the polarization may occur in curved lines, and induction take place round corners and behind obstacles.

Fig. 66.

Polarization of atoms.

**185. Sources of electricity.**—These are various. Besides ordinary friction, the rubbing of water particles against the aperture when steam escapes is a powerful source of electricity. Whenever bodies are pressed together and separated, they exhibit traces of opposite electrical excitement. Many crystals are made electric by mere compression; Iceland spar pressed between the fingers becomes excited. If tourmaline be slowly heated, it becomes powerfully excited, as is represented in Fig. 67 (No. 1). When the heat is no longer added, the excitement disappears, but, as it cools, the electrical conditions are reversed (No. 2). That the particles are polarized through the whole length is shown by the fact that if the crystal be broken, as the temperature falls each piece is electrified (No. 3). Fracture, crushing, and combustion, all produce electricity. Carbon in burning is negative, while the carbonic acid formed is positive.

Fig. 67.




Tourmaline electrified by heat.

## § IV. *Voltaic Electricity—Electro-Dynamics.*

**186.** We have now to consider electricity in a state of motion and active force. This important branch of the science was discovered about 1790, by Galvani, while working with some dissected frogs, and in his honor is frequently called *Galvanism;* but

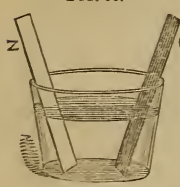
this view what is insulation? 185. What other sources of electricity are mentioned? What does Fig. 67 represent? 186. What is electro-dynamics? Who

its most illustrious cultivator was VOLTA, whose name is inseparably connected with its foundation and progress, and from whom it is also called *Voltaic electricity*. Both these celebrated men were Italians.

**187. Sulzer's experiment.**—It was noticed by SULZER, about a hundred years ago, that, if a silver coin be placed upon the tongue, and a piece of zinc beneath, a peculiar tingling sensation or taste will be perceived when the ends of the metals are made to touch; or, if the silver be pressed between the upper lip and the teeth, a flash of light will be observed when the metallic contact is made. This is an effect of voltaic electricity.

**188.** We have just stated that electrical disturbance may arise from simple contact of different substances. VOLTA supposed that these effects were due to the same cause. But it is now generally considered that when electricity arises by metallic contact, it is owing to chemical change. Voltaic electricity is produced when two unlike solids, usually metals, are immersed in a liquid which dissolves only one of them. It is a general law that no chemical action occurs unaccompanied by electrical disturbance, although the quantity is often so minute as to escape detection.

FIG. 68.




No effect.

FIG. 69.

The voltaic circuit.

**189. The Voltaic Circuit.**—A strip of zinc and one of copper are placed in a vessel containing water, to which has been added a little sulphuric acid. If not permitted to touch each other, as in Fig. 68, there is no effect. But if brought into contact, as seen in Fig. 69, several results ensue. The acid in the water grows weaker; the zinc strip is corroded, wastes away, and bubbles of gas are seen to escape from the surface of the copper. If the metals are separated, the action ceases; and, if this is done in the dark, a minute spark will be seen. Electricity seems to flow round and round in the direction of the arrows, like an invisible stream. The combination through which it passes is termed a *voltaic circuit*, and the circulating force an electric, or electromotive current. If the plates

discovered it? Why is it called voltaic electricity? 187. What was SULZER'S experiment? 188. When is voltaic electricity produced? What is said of chemical

be connected by means of a wire, which may be a few inches or many miles in length, a current passes through the whole distance. If a non-conductor be substituted for the wire, the action instantly ceases.

**190.** The source of the electricity is the decomposition of the water, its oxygen combining with the zinc to form oxide of zinc, while hydrogen gas is set free. But the oxide of zinc is insoluble, and would form an impervious coating upon the plate, and quickly stop the process. This is prevented by the sulphuric acid which unites with the oxide, forming sulphate of zinc, and thus the plate is kept clean and the action maintained till the metal is consumed, or the acid all neutralized.

**191. Amalgamation.**—A slip of pure zinc introduced into the acid is but slightly, if at all, acted upon. But commercial zinc is contaminated with lead and other metals, the effect being to create minute currents between them and the adjacent particles of zinc, thus corroding the plate and wasting the electric force. To prevent this, the clean zinc surface is rubbed over with a little mercury, which forms an amalgam with it, increasing the energy of the zinc, and enabling it to be kept in acid without corrosion.

**192. Electrodes.**—To the plates are usually soldered wires with terminals of platinum to withstand the action of corrosive liquids. The ends of these wires are known as the *poles* of the circuit, from an idea that they exerted an attractive and repellant action, like the poles of a magnet. But FARADAY has proved that there is no attraction or repulsion in the case, and suggested the better term *electrodes*, which means simply a door or way for the electricity.

**193. Positive and negative parts of the circuit.**—The terms positive and negative have a double application to different parts of the circuit, which often confuses the student. The copper pole is positive (which may be easily remembered by associating the four p's of the three words), and the zinc pole negative. But these terms are reversed when applied to the plates—zinc being now positive and copper negative. Whatever be the metals used,

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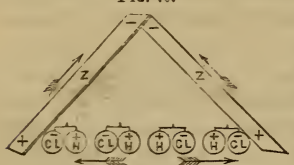
action? 189. Describe the voltaic circuit? Its effects? 190. What is the source of the electricity? What is the office of the sulphuric acid? 191. What difficulty arises in the use of common zinc? How remedied? 192. What are the poles of the circuit? Why is 'electrodes' the better term? 193. How are the terms positive and negative applied? Where does the positive electricity originate, and what is

the positive plate, or the one chemically acted upon, originates positive electricity, which passes over to the negatively affected plate, and is by that *delivered* at the positive electrode.

194. **Polarities of the circuit.**—The electric current originates in chemical changes, and requires a compound liquid capable of decomposition by one of the metals. To bring the chemical force into play, the voltaic circuit must be arranged so as to form a continuous chain of polarities. The theory of the action may be illustrated by representing the atoms of the liquid to the eye. A plate of zinc with one end in chlorohydric acid assumes a state of electrical tension, and induces the same state in the atoms of hydrogen and chlorine which compose the acid, Fig. 70. The positive zinc attracts the adjacent atom of negative chlorine, but not with sufficient force to take it from the positive hydrogen. Nor is the matter helped by completing the circuit with another zinc plate, as shown in the figure. At two points, above and below, like electricities repel each other; the tensions are balanced, and there is no motion.

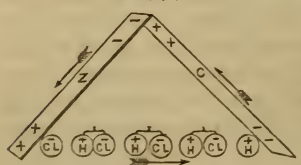
FIG. 70.




Polarity, but no current.

195. But if now the second zinc plate be replaced by one of copper, the conditions are altogether changed; the polarities are unlocked, the liquid is decomposed, and there is an active circuit, as illustrated in Fig. 71. The copper imparts an additional amount of positive electricity to the zinc, the tension of which is thus heightened, and receives a portion of negative electricity in return. A powerful polar influence is thus communicated to the liquid. The increased attraction of the zinc causes it to decompose the adjoining atom of acid, combining with the negative chlorine; while the atom of hydrogen, powerfully polarized by induction, acts in the same way, decomposing the next

FIG. 71.



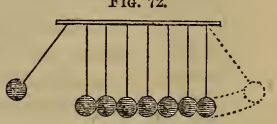

Conditions of circulation.

its course? 194. In what does the electric current originate? What does it require? What is the effect of one zinc plate in the acid? Of two? 195. What is the effect of replacing the zinc by a copper plate? Draw Figures 70 and 71 upon

atom of acid, uniting with its chlorine, and forming a new compound atom. This is repeated through the series, and the last atom of hydrogen, having its positive electricity neutralized by the strongly negative copper, is set free.

**196. Currents.**—Here again we are in danger of being misled by terms which involve material views of force. The word 'current' is to be used in a sense entirely figurative. In dealing with subtile, invisible forces, it is easiest to view them through the medium of analogy and apply terms borrowed from sensible objects. The effects of electricity resemble those of a stream, and from appropriating the terms we gradually acquire the idea of an unseen but real fluid flowing in currents through substances, or from one to another. But all we know in the matter is *progressive effects*, and all we are entitled to assume is the *progress of force.* The movement of electricity is more analogous to that of sound, where pure impulse and not matter is borne forward. (319) If the ivory ball at one extremity of a closely suspended series, Fig. 72, be raised and let fall, the one at the other end will be struck off, the intervening balls remaining in their places, yet transmitting the impulse; there is only a progress of force. While the term current in electricity is convenient and perhaps indispensable, we mean by it the same as if we should speak of a current of sound, or, in the case of the ball, a current of motion.

FIG. 72.



Elastic balls.

**197. Two Opposite Currents.**—We have seen that electricity, like magnetism, is a polar force, displaying itself in a twofold way. When produced in the voltaic circuit, it separates into two equal and opposite powers—two currents which, when they meet, instead of doubling, neutralize each other. The electricity thus produced has been likened to a double-headed arrow rapidly elongating itself in opposite directions. At first they move from each other, but turning through equal semicircles, they meet, each arrow-head destroying the other.

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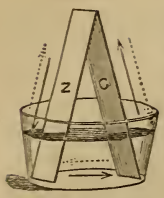
the blackboard, and explain them. 196. In what danger are we from using the word current? What do we really know in the matter? To what is the movement of electricity analogous? To what else is it compared? 197. In what respect have we seen electricity to be like magnetism? To what are the movements of the current likened? What is meant when the direction of the current is spoken of?

Fig. 73.

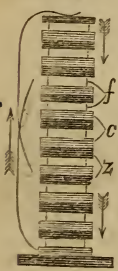



The two currents.

The two opposite electricities or polarities constantly meet and neutralize each other, and are constantly renewed. To avoid confusion, when the direction of the current is spoken of, the positive alone is indicated. In Fig. 73 the dark arrows show the direction of the positive current, the dotted arrows that of the negative.

**198. The Voltaic Pile.**—The power of the circuit may be increased by repeating its elements. The pile discovered by Volta and named after him was the first contrivance for augmenting the force of the electric current. It is made by preparing small plates or discs of metal, usually copper and zinc, and placing between them pieces of flannel moistened with an acid or saline solution. Such a pile is represented in Fig. 74. The cloth is placed between the metals, and the order begun is preserved. Commencing at the bottom there is copper (c), flannel (f), zinc (z), and upon that copper, flannel, zinc, and so on to fifty or a hundred sets, as may be desired, 74. The lower or copper end is positive, and the other negative; a current therefore moves in the direction of the arrows. This form of instrument gives a strong effect at first, but rapidly declines in power.

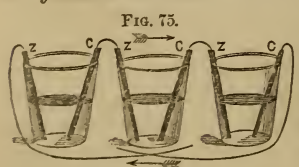
Fig. 74.




Voltaic pile.

**199. The Galvanic Battery.**—To augment the electrical effect, and at the same time secure steadiness of action and convenience of management, the compound circuits are arranged in other forms known as *voltaic* or *galvanic batteries*. A series of cups or cells, containing an acidulated liquid, are arranged, in each of which there is a plate of copper and another of zinc; the copper plate of one cup being connected by a copper wire with the zinc plate of the preceding cup, Fig. 75.

Fig. 75.




Voltaic battery.

**200. Smee's Battery.**—We have already noticed the tendency

198. How may the force of the circuit be increased? What is the voltaic pile? Explain Fig. 74. 199. What objects are secured by the galvanic battery? How is it made? 200. What hindrance is overcome by Smee's battery? How is it done?

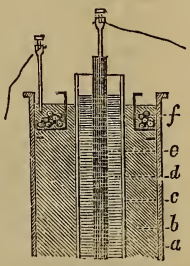
of gases to condense upon solid substances. In the battery a film of hydrogen forms in this way upon the smooth copper and platinum, which is a serious hindrance to the action. If, however, the surface be roughened, it passes off with ease. SMEE removed this difficulty by using a silver negative plate, and coating it with platinum black. To form the single cell, two plates of amalgamated zinc are clamped against a piece of wood with a silver plate between them, Fig. 76. They are then suspended in a glass vessel, the piece of wood resting upon the top. The liquid used is sulphuric acid diluted with ten or fifteen times its weight of water. A binding screw attached to the silver plate connects the positive wire, and another from the zinc plate the negative. A series of these cells properly joined, or a series of connected plates immersed in a suitable trough, constitutes SMEE'S *battery*.

FIG. 76.

Smee's cell.

**201. Daniell's Battery.**—Prof. DANIELL made an important improvement in the battery by using two different fluids separated by a porous partition. Fig. 77 exhibits a section of Daniell's cell; *a* is an outer cylinder of copper filled with *b*, an acid solution of blue vitriol, which is kept saturated by crystals resting upon the perforated shelf *f*; *c* is a tube of porous ware, or unoiled leather, filled with *d*, 1 part of sulphuric acid to 7 water, and into this is plunged a rod of amalgamated zinc *e*. To the copper and zinc are attached binding screws for wire connections.

FIG. 77.




Daniell's cell.

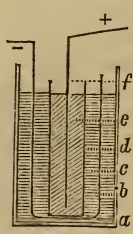
**202.** The blue vitriol consists of sulphuric acid and oxide of copper. When the action commences a double set of changes takes place in the liquid. Oxide of zinc is formed in the inner vessel, and the polarizing action taking place through the porous wetted body *e*, the sulphate of copper is decomposed in the outer vessel. The sulphuric acid set free is gradually transferred to the inner vessel, while the hydrogen, instead of being set free, combines with the oxygen of the oxide of copper, precipitating metal-

How is a single cell constructed? What liquid is used? How are the wires attached? 201. In what did Prof. DANIELL'S improvement consist? Describe his cell. 202. Explain its mode of action. What is said of it? 203. How does

lic copper upon the surface of the outer cylinder. This was the first constant battery, and is capable of maintaining a uniform strength for many hours.

**203. Grove's Battery** is also an arrangement for two fluids, like DANIELL's, its metals being amalgamated zinc and platinum, and its liquids nitric and sulphuric acids. Fig. 78 is a vertical section; *a* is a jar of earthenware, *c* the outer liquid of dilute sulphuric acid; *b* is a cylinder of amalgamated zinc connected with the negative electrode, and having a slit on one side to allow the free passage of the liquid. It is therefore exposed on both sides to the outer liquid *c* of dilute sulphuric acid; *d* is a cup of unglazed earthenware filled with strong nitric acid *e; f* is a thin slip of platinum suspended in the porous cup, and connected with the positive electrode.

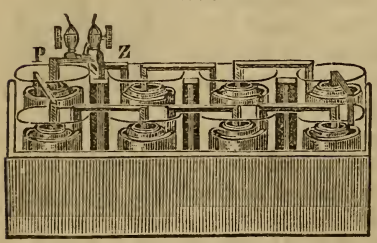
FIG. 78.




Grove's cell.

**204.** In GROVE'S *battery* the oxygen combines with the zinc, as in the other cases, but the hydrogen decomposes the nitric acid, unites with a portion of its oxygen, forming water and producing deutoxide of nitrogen, which rises into the air, and, reuniting with oxygen, forms nitrous acid fumes. The escape of these corrosive vapors is a disagreeable feature of this combination. Figure 79 represents a series of cells in working connection. GROVE'S battery produces very powerful and brilliant effects, and is much used in telegraphy. It is less constant than DANIELL'S, but according to Prof. JACOBI, when the platinum and copper surfaces are equal, that of GROVE is 17 times more powerful.

FIG. 79.




Grove's battery.

**205. Bunsen's Carbon Battery** is similar to GROVE'S, but replaces the expensive platinum by cheap carbon cylinders made by

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GROVE'S battery differ from the preceding? 204. Explain its action. What is said of it? 205. What is BUNSEN'S battery? Of what does the MAYNOOTH battery

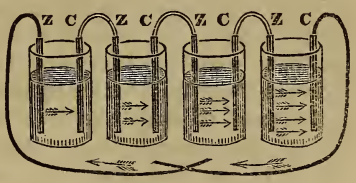
pulverizing gas-carbon (526), mixing it with flour, and baking it into hard pieces. Dr. CALLAN'S *Maynooth battery* consists of a water-tight cast-iron cell, containing a porous cell, in which is a plate of amalgamated zinc. Mixtures of strong sulphuric and nitric acids are used, and the effects are claimed to be more intense even than those of GROVE'S battery. SCHÖNBEIN'S *battery* resembles the one just described, except that the outer cell is formed of *passive* iron, which makes an excellent combination with zinc (794).

**205. Resistance to the current.**—As in machinery all the force applied is not available for work, some of it being absorbed by friction, so all the electrical force generated in the battery cannot be made available for effect, a portion of it being destroyed by resistance of the materials of the circuit itself. The conductors are to a certain extent also obstructors. The resistance is, first, that of the liquid of the battery, which depends upon its conducting quality, and the distance between the plates. The larger the plates and the closer together, the less the resistance. Second, the wires offer a resistance dependent upon their length, narrowness, and material.

**207. Quantity and Intensity.**—These terms describe two contrasted states of electrical manifestation, the meaning of which may be illustrated by reference to heat. Thus the heat in the human body is considerable in quantity, but low in intensity, while that of an ignited match is very small in quantity, but high in intensity. Of course there can be no electricity that does not possess to a certain degree both qualities, but one or the other is always in great excess.

**208.** In the battery the quantity of electricity depends upon the *size* of the plates; the intensity upon the *number* of them. If we increase the *size* of a pair of zinc and copper plates, we increase the quantity of the electricity they produce, but not its in-

FIG. 80.




Accumulating intensity.

consist? SCHÖNBEIN'S? 206. In what respect does the battery resemble machinery? Where is the resistance, and on what does it depend? 207. What is meant by quantity and intensity in electricity? Do they exist together? 208. Upon what does the quantity of electricity in the battery depend? The intensity?

tensity; while, if we reduce the size, we reduce the quantity, the intensity remaining the same. On the contrary, if we multiply the *number* of pairs of equal size, the intensity is augmented at an equal rate while the quantity is unchanged. The electricity developed by a single pair is exceedingly feeble; the second cell adds no more to it, but intensifies its power. In Fig. 80 the arrows illustrate the accumulating intensity.

209. **Frictional and current electricity.**—It has been demonstrated that frictional and current electricity are one; all the effects of the former being produced by the latter. But these modes of action are marvellously different. We may view a spark as a fraction of a current; and a rapid succession of sparks as an imperfect approach toward a current. But the duration of a spark is infinitely small compared with the time necessary to accumulate the electricity which produces it. A six-inch electric spark is estimated to pass in the three thousand millionth part of a second (WALKER), but no frictional machine can supply a beginning to three thousand million such sparks in a second. The machine of the London Polytechnic Institute, with an 87-inch plate driven by steam at 80 revolutions per minute, and a friction of 90 square feet of glass per second, gave the six-inch sparks no faster than they could be counted. The quantity is thus small, and the intensity high. But in the voltaic circuit, charge is as instantaneous as discharge; the stream is unbroken; the quantity is enormous, but the intensity low.

210. **A flash of lightning in a drop of water.**—Dr. FARADAY demonstrated that the electric current which is required to decompose a single grain of water is also sufficient to keep a platinum wire the $\frac{1}{100}$th part of an inch in diameter red hot for $3\frac{3}{4}$ minutes. But to produce the same effect for the same time by frictional electricity would require 6,500,000 discharges from a Leyden jar 8 inches high and $7\frac{1}{2}$ inches in diameter. It would, therefore, require this amount of static electricity to decompose a single grain of water. Dr. FARADAY further showed that this would suffice to charge an insulated conducting pane, such as a thunder-cloud,

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How may we vary either? What does Fig. 80 represent? 209. In what respects are current and frictional electricity alike? How does the duration of a spark compare with the time required to accumulate it? What instance is given? How is it in the voltaic circuit? 210. How much voltaic electricity is required to decompose a drop of water? How much frictional electricity is this equal to?

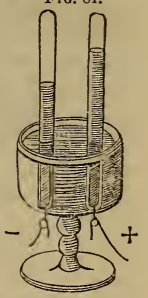
thirty-five acres in area, the instantaneous discharge of which would constitute a powerful flash of lightning.

**211.** Voltaic electricity will travel through a conductor thousands of miles rather than penetrate a barrier of air a small fraction of an inch in thickness, while static electricity will leap through miles of intervening atmosphere. For sustained effects, as in chemical decompositions and telegraphy, where vast *quantities* of electricity are required, the battery is employed, its current being raised to the requisite tension by multiplying the cells.

## § V. *Effects of Voltaic Electricity.*

**212. Decomposition of water.** If the ends of the platinum wires connected with a battery are placed near each other in a vessel of water containing a little sulphuric acid to aid conduction, bubbles of gas will be seen to rise from the terminals and escape at the surface. A couple of glass tubes filled with water, and inverted in the vessel over the poles, serve to collect the rising gases, Fig. 81, which upon examination prove to be pure hydrogen and pure oxygen, the bulk of the former being twice that of the latter. The water becomes part of the circuit, and is decomposed by a polarization of the line of compound particles between the electrodes in the same manner as occurs in the battery itself (195); only in this case, as the oxygen does not combine with the platinum, it is set free like the hydrogen.

FIG. 81.




Electrolysis of water.

**213. Electrolysis.**—This operation is termed electrolysis (analyzing by electricity), and any substance that is capable of this decomposition is called an *electrolyte*. Solids are not electrolytes. Liquids, and certain liquids only can be electrolyzed. A good electrolyte should be a good conductor, and yield upon separation a conductor and a non-conductor. The binary compounds are resolved into their elements by the current, and the salts into acids and bases. Sulphate of soda yields sulphuric acid at the + pole, where it may be made to redden vegetable blue, while soda

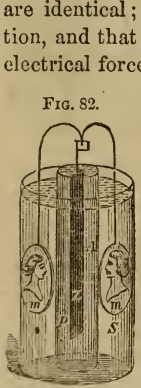
211. How do they differ in power to penetrate the air? For what is the battery used? 212. How is the decomposition of water effected by the current? Explain Fig. 81. 213. What is electrolysis? What bodies are good electrolytes? Exam-

appears at the — pole, and will there turn vegetable reds to blue By reversing the direction of the current, these beautiful effects are also reversed.

**214.** When compounds are electrolyzed their elements are found in opposite electrical states. Some, as oxygen, chlorine, sulphur, appear at the positive electrode, and are called electro-negative bodies; while others, as hydrogen and the metals, appear at the negative electrode, and are called electro-positive. Of the 64 elements, 24 are usually ranked as electro-negative, and 40 as electro-positive. Oxygen heads the first list, or is the most powerful electro-negative body, while the newly discovered cæsium heads the other, being the strongest electro-positive substance. The elements may be arranged in such an order that each will be electro-negative to all which follow it, and electro-positive to all which precede it.

**215.** As the electric current thus originates in chemical changes and produces them, and as the atoms seem to be in opposite electrical states, it is obvious that electrical force is very closely allied to chemical power. The *electro-chemical theory* teaches that they are identical; that electrical attraction causes chemical combination, and that every chemical decomposition is due to the play of electrical forces.

Fig. 82.



Electrotyping.

**216. Electrotype** is the name given to the process of depositing metals from their solutions by electricity. The deposited metal assumes with exactness the form of any body upon which it is made to settle, so that when removed it forms a perfect counterpart of the object, copying and reversing all its markings and irregularities. To copy a medal it is first made perfectly clean, and the back and edges protected by a coating of varnish or wax. The battery used may be of various forms; Daniell's cell, Fig. 82, answers the purpose. Into a glass tumbler, *S*, is introduced a lamp chimney, A P, with a piece of bladder tied over the lower end. This is filled with dilute acid, while the tumbler contains a strong solu-

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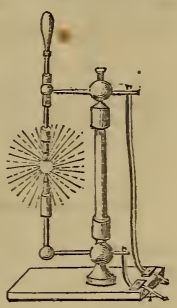
ples. 214. How is the division of the elements into electro-negative and electro-positive effected? How are they proportioned to each other? How may the elements be arranged? 215. What is the electro-chemical theory? 216. What is

tion of sulphate of copper. The medals *m m* are immersed in the sulphate of copper, and connected by wires to the zinc rod Z. Thus arranged, the sulphate of copper is gradually decomposed, and the metal evenly deposited. The copper coating is then detached, and forms a perfect reverse or mould of the object. The whole process is then repeated with the mould, producing an exact copy of the original medal.

**217.** In *electro-gilding* and *electro-plating* the object is to impart a new and permanent metallic surface. In this way numberless articles placed in solutions of silver and gold are coated with these metals, from the thinnest gilt to the thickest plating.

**218. Heating effects of the current.**—A current passing through a conductor raises its temperature in proportion to the electricity arrested. This depends first upon the quantity in motion, and second upon the resistance offered by the conductor. A wire which is but little heated by a current, if considerably reduced in diameter, becomes instantly white hot. The arrested electricity appears as heat. Two charcoal points brought into contact in the circuit, and then slightly separated, emit a light of dazzling splendor, Fig. 83.

Fig. 83.



Electric light.

**219. The electric light.**—The brilliancy and purity of the electric light from charcoal points and the absence of contaminating products make it highly desirable as a source of illumination. But there is a mechanical difficulty in the way of its use. Particles of carbon are constantly transferred from the positive to the negative poles; one is shortened and the other lengthened, and that unequally, so that it is troublesome to maintain them at the precise distance.

**220. Blasting.**—By passing a fine platinum wire through a charge of gunpowder, it is instantaneously exploded by the current. The same wire may pass through several charges and ignite them simultaneously. In excavating for an English railway, nine tons of gunpowder were buried in three masses in the Dover Cliffs,

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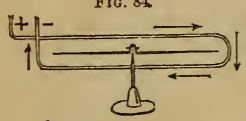
the electrotype? Describe the process. 217. What is the object in electro-gilding and plating? 218. When electricity is arrested by a conductor, what becomes of it? Upon what does the amount of heat depend? 219. What are the advantages and disadvantages of electric light? 220. How is the electric

from 50 to 70 feet from the surface, and ignited by a distant battery. The explosion detached 600,000 tons of the chalky cliffs. Powder is fired in the same way for blasting rocks under water.

## § VI. *Electro-Magnetism.*

221. In 1820, Prof. OERSTED, of Copenhagen, discovered that if a magnetic needle be brought near a wire along which an electric current is passing, the needle will be influenced and caused to move. The degree of the motion will depend upon the strength of the current, and its direction upon the relative position of the needle and wire. If the wire be above and parallel to the needle, the pole next the negative electrode will move westward; if beneath the needle, it will move eastward. If the wire is on the east side, this pole will be elevated; if on the west, it will be depressed. In all cases it tends to place itself at right angles, or transverse, to the wire. If the wire be bent, so as to pass above and below the needle, Fig. 84, the effect is increased; and if it be coiled round many times in the same manner, it becomes still more powerful. The motion of a needle thus freely suspended becomes the visible test of an electric current.

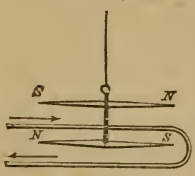
FIG. 84.




Current and needle.

222. **The Astatic Needle.**—But a needle keeps its place in the magnetic meridian with considerable force, so that a very faint current will not move it. If two needles, however, are placed parallel, near each other, with reversed poles, their directive force is mutually neutralized. Two needles thus fixed upon an axis, Fig. 85, form the *astatic* (unstable) *needle*. If one is slightly stronger than the other, it still retains a feeble tendency to keep its north and south position. If now the wire of Fig. 85 were folded round both these needles, the same current would urge them in opposite directions, and there would be no motion; but when the coil incloses only one of the needles, as the lower for example, the current impels

FIG. 85.

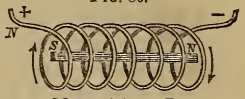



Astatic needle.

current used in blasting? 221. What was Prof. OERSTED'S discovery? Upon what do the degree and direction of the motion depend? 222. What is the astatic

both needles in the same direction. If the needles be delicately suspended, it affords the means of detecting the faintest electrical current and forms the *galvanometer*.

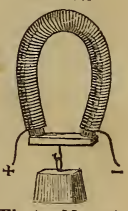
Fig. 86.




Magnetizing a Bar.

**223. Electro-Magnets.**—If a bar of steel be placed in a coil of wire, as in Fig. 86, and a current be sent through the coil, the bar becomes at once permanently magnetic. If a bar of soft iron be introduced, it becomes magnetic, but only continues so as long as the current is maintained. A horse-shoe bar of soft iron, with a wire twisted spirally round it, as in Fig. 87, becomes a powerful magnet, capable of supporting a heavy weight, while the current is passing.

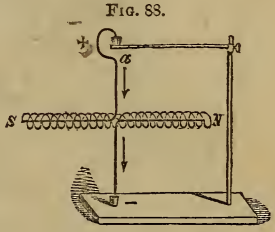
Fig. 87.




Electro-Magnet.

**224. The Current a Magnet.**—Electric currents attract and repel each other like magnets. When two wires are freely suspended near each other, if currents pass through them in the same direction, they attract each other; if in opposite directions, they repel each other. If a copper wire be coiled into a spiral, Fig. 88, and the extremity, *a*, hooks into a cup of mercury, while the other end dips into a second cup, the coil will be free to move in any horizontal direction. If now a current be transmitted through the coil, it arranges itself *north and south*, just like the needle, and it will be attracted and repelled by another similar coil in the same manner as two magnets. Hence Ampére assumes that magnetic polarity is caused by electric influence, perpetually circulating round the particles of which the magnet is composed.

Fig. 88.




Polarity of the Current.

**225. Induced Currents.**—If two conductors are placed near and parallel to each other, a current sent through one induces an opposite current in the second. At the moment the circuit is formed and the primary current passes, a secondary current is produced in the opposite direction in the second wire.

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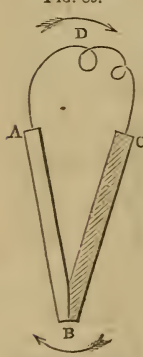
needle? What is the galvanometer? 223. What do Figures 86 and 87 represent? 224. How do electric currents affect each other? Explain Fig. 88. What does

**226. Electro-magnetic Telegraph.**—This remarkable contrivance consists of three parts: a battery for supplying the motive power, an insulated metallic line between the points to be connected, and an apparatus for signalling, or registering messages. Two wires were at first thought necessary to complete the circuit, but it was early found that the earth might be made to replace one wire if the other was connected with the ground at both ends. The electrical impulse which traverses the wire circulates round a bar of soft iron, magnetizing and demagnetizing it as often as the connection with the battery is made and broken, and thus motion is communicated to the recording machine.

**227.** We must not forget that there is nothing like a current through the telegraph wires. We may be aided to understand what takes place by imagining a small tube, connecting two places, closely filled with a row of peas. As a pea is pushed in at one end, another falls out at the opposite end, although it is evident that nothing but *motion* has passed. But motion may pass although each pea keeps its position, if we suppose them all linked together by attractions upon their different sides. If the first pea were *turned upon its centre*, it would turn in like manner the whole series. The peas may represent the atoms of the telegraphic circuit, and their motions the polarization of particles by which the effect is communicated. The wire of the circuit communicates its polarity to the bar of soft iron around which it is wound; this becomes magnetically polarized, and attracts the marking lever of the recording machine.

FIG. 89.




Thermo-electric Pair.

## § VII. *Thermo-Electricity.*

**228. The Thermo-electric Pile.**—As electricity produces heat, so heat in turn produces electricity. A B, Fig. 89, is a bar of antimony, and B C a bar of bismuth soldered together at one extremity, and connected by the wire D at the other. When the place of junction is warmed an electric current is produced, which moves

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Ampère assume? 225. Explain what is meant by induced currents. 226. Of what parts does the electro-magnetic telegraph consist? How is motion obtained? 227. Give the illustration of the peas. 228. Describe the thermo-electric pair,

in the direction of the arrows. If the junction B is chilled, the current moves in the opposite direction. Such a combination forms a *thermo-electric pair*. The effect is increased if several of these are united, forming what is known as the *thermo-electric pile*. To secure a compact arrangement, they are soldered together as in Fig. 90, and then combined as in Fig. 91, A representing one of the faces of the pile. When both faces are equally heated, there is no current. If the face, A, is warmed, there is a current in one direction due to the difference of temperatures between the two faces. If the opposite face is warmed; or, what is the same thing, if the face, A, is cooled, there is a reverse current.

Fig. 90.

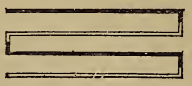
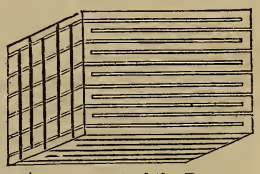


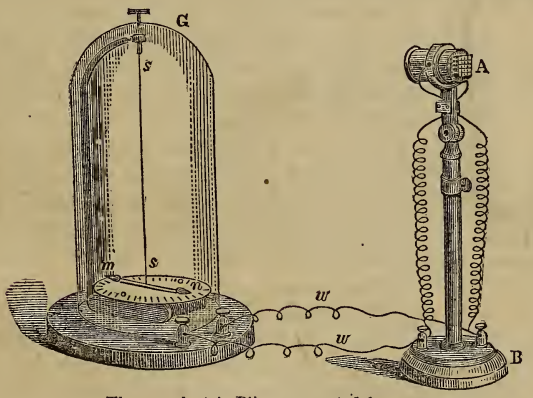
Fig. 91.




Arrangement of the Bars.

**229.** In Fig. 92, A B represents the thermo-electric pile as

Fig. 92.




Thermo-electric Pile as mounted for use.

mounted for lecture-room use. A shows one of the faces; w w are wires connecting it with the galvanometer. The needle m n

Fig. 89. Explain the construction and action of the *thermo-electric* pile. What does Fig. 90 represent? 229. Describe the pile as mounted for lecture-room

is suspended by a fibre S S of unspun silk, and protected from currents of air by the glass shade G. To one end of the needle is fixed a piece of red paper, and to the other a piece of blue. If the face of the pile is merely breathed upon, the warmth swings the needle round to 90°, or at right angles to the current,—the pieces of paper making the movement visible throughout the room. This important instrument was invented by NOBILI, and applied with remarkable success to researches in heat by MELLONI. It detects heat radiation from sources much lower than the human body, and announces the heat emitted from the bodies of insects. How wonderful, that the minutest quantity of heat we can detect, only appears after it has been first converted into electricity, then into magnetism, and then into mechanical motion!

**230.** As the earth constantly turns upon its axis, the sun heats its mineral constituents unequally, which must give rise to east and west electrical currents, and, as the magnet tends to place itself across them, we see the reason for the direction of the needle. The earth's magnetism appears thus caused by the action of the sun.

FIG. 93.

Spark from Magnet.

**231. Magneto-Electricity.**—As electricity produces magnetism, so magnetism may produce electricity. If a bar of soft iron be introduced into a coil of wire, and a magnet be made to approach the bar, it is magnetized by induction, and at the same time a momentary current is produced in the surrounding wire. This is more simply shown by winding the armature of a horse-shoe magnet, Fig. 93, with a piece of copper wire, one end of which is flattened and the other sharpened. Whenever the armature is removed or replaced, a spark is produced at C, indicating a current through the wire.

**232. Induction Coils.**—If one or two hundred feet of stout copper wire are wound into a close coil, and then twenty or thirty thousand feet of much finer wire (both well covered with silk) be wound into a secondary coil around the first, a current sent through the inner wire and rapidly interrupted, induces very powerful currents in the outer coil, which give rise to

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use. What is said of it? 230. How is the direction of the needle explained? To what is the earth's magnetism due? 231. How may electricity be produced by magnetism? 232. What is the principle of RUHMKORFF'S *coil*? What

a stream of brilliant sparks. This is the principle of RUHMKORFF'S *coil*, one of the most energetic electrical machines yet devised, producing electricity in large quantity and of extraordinary intensity.

**233. The Stratified Discharge.**—If electricity be sent through an ordinary vacuum, the spark is changed to a diffused auroral glow. But when the vacuum becomes more perfect, the light appears *stratified*, or broken up into numerous rings or plates. GASSIOT sealed platinum wire in glass tubes, and, by using an atmosphere of carbonic acid which was first exhausted by the air pump, and the residue gradually absorbed by caustic potash, he produced a very perfect vacuum. When the rarefaction is carried a step further than can be done with the air pump, on discharging a Ruhmkorff coil through it, narrow bands transverse to the line of discharge are seen, as in Fig. 94. Increasing rarefaction widens the bands, and gives them a conical shape, as in Fig. 95, and, as the vacuum becomes more perfect, a series of luminous cylinders of an inch or more in depth appear, divided by narrow dark lines, Fig. 96, till at last, when the vacuum becomes perfect, discharge light and conduction cease. It seems thus proved that a vacuum, instead of being a good conductor, as was formerly supposed, is a perfect non-conductor, and that the *presence of matter* is indispensable to the manifestation of electrical force.

FIG. 94.

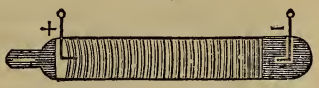
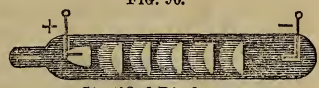



FIG. 95.

FIG. 96.




Stratified Discharge.

## § VIII. *Animal Electricity.*

**234.** It was known to the ancients that certain fishes have a peculiar power of benumbing animals. It has been found that they possess electrical organs or batteries by which they can give powerful shocks, which produce all the effects of ordinary electricity. Fig. 97 represents the torpedo with its electrical organs,

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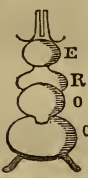
is said of it? 233. How does electricity appear in an ordinary vacuum? When the vacuum is more perfect? In the most perfect? What does this prove?

*a a*, laid bare. They are situated on each side of the head, and are composed of five or six sided prisms, extending vertically from the lower to the upper side of the fish. They are divided in horizontal partitions, so that the whole resembles a mass of honeycomb, the cells being filled with a dense fluid consisting of water, albumen, and a small portion of common salt. These organs form a *living battery*, and are the source of electrical force, just as the muscles are of mechanical force. A dense mass of nerves links them with the brain, which has *control* of the discharges the same as of muscular movement. The seat of control is the electrical lobe; if this be uninjured the animal may be skinned, its heart cut out, and the other portions of the brain extirpated, without loss of the faculty.

Fig. 97.

Electrical Organs of the Torpedo.

Fig. 98.

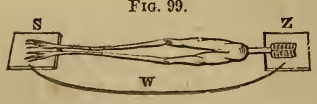



Brain of Torpedo.
C, Cerebrum.
O, Optic Lobe.
R, Cerebellum.
E, Elect. Lobe.

**235. Galvani's** well-known experiment with the frog was the starting-point of modern research in this branch of electricity. The legs of the frog are detached from the body, the skin removed, and the lumbar nerves exposed. They are then laid upon a glass plate with a small piece of zinc Z, Fig. 99, placed under the nerve, while the feet rest on a thin slip of silver. They are dead and powerless, but if now a wire, W, be made to touch the pieces of metal, so as to form a connection between muscle and nerve, the legs instantly contract and kick away the silver.

**236. Human Electricity.**—As it is now admitted that no chemical change can occur without electrical excitement, and as the human body is a mass of rapidly changing chemical materials, it must be a theatre of extensive electrical movements, though to

Fig. 99.

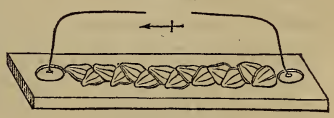



Experiment with Legs of Frog.

234. Describe the electrical apparatus of the torpedo? What is its relation to the brain? 235. What is said of GALVANI'S experiment? How is it performed? 236. What difficult problem is stated to be now demonstrated? What has been proved by MATTEUCCI? By DUBOIS-REYMOND? What was his experiment with the frogs?

demonstrate this has been one of the most delicate and difficult problems of science. The blood is an alkaline liquid, while the juice of flesh is acid, and the two liquids are only separated by the thin walls of the vessels. By the action of these fluids there must be in every mass of muscle myriads of electric currents. MATTEUCCI has proved that currents of electricity are always circulating in the frames of all animals, and that a positive current is continually passing from the interior to the exterior of a muscle. The smallest shreds of muscular tissue have been proved by DUBOIS-REYMOND to manifest currents, the longitudinal section being always positive to the transverse section. By arranging a series of half thighs of frogs, alternately connecting the exterior and interior surfaces, Fig. 100, he obtained a current that decomposed iodide of potassium, deflected a magnetic needle 90°, and caused the gold leaves of an electroscope to diverge.

FIG. 100.



Muscle Battery.

# CHAPTER IV.

## HEAT.

### § I. *Thermal Expansion—Thermometers.*

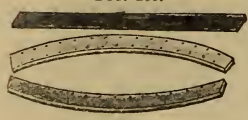
**237.** THIS well-known force has an almost omnipotent control over the states of matter; it is an all-determining agency in nature, and is so essential to the numerous processes of the laboratory that the chemist has been called the 'Philosopher by Fire.' The general science of heat is termed *Thermotics*, from the Greek *thermos*, hot, which gives us also the words *thermal*, *thermometer*, &c.

**238. Expansion of Solids.**—The general effect of heat upon matter is to expand it. The copper ball, Fig. 9, p. 36, when heated, enlarges and rests upon the ring; when cooled, it shrinks and falls

237. What has the chemist been called, and why? What is thermotics, and whence is the name derived? 238. What is the general effect of heat upon matter? What

through it. The copper, and all bodies of uniform atomic condition, expand equally in all directions, while other substances, as crystals and wood, in which the atoms are differently arranged in different directions, expand unequally (267). With a given amount of heat force, the same substance always expands to the same degree; but the same quantity of heat causes different substances to expand unequally. This may be shown by riveting together thin slips of different metals, for instance brass and iron, into a straight bar, Fig. 101. When dipped into hot water it is warmed, and the brass, expanding most, becomes longest; the bar curves, the brass forming the convex side. If placed in ice water, the brass contracts most, and the bar curves in the opposite direction. Heat, which drives atoms asunder, is thus the antagonist force to cohesion: and a quantity of heat applied at a high temperature, produces more expansion than the same amount at a low one;—the cohesion in the first case being partially overcome.

FIG. 101.



Expansion of Compound Bars.

**239.** The expansion of solids, though small, takes place with tremendous force. The Bunker Hill monument has a slight daily motion as the sun expands its sides. The ponderous iron tubes of the Britannia bridge lengthen and shorten, and writhe and twist like a huge serpent, under the varying influence of solar heat. One of the tubes, 400 feet long, is depressed in the centre but a quarter of an inch by the heaviest train of cars, while the sun, expanding its upper side from morning to noon, elevates it in the centre two inches and a half! Wheel tires and iron hoops are made smaller than the frames they are to surround, and put on while red hot, their contraction on being suddenly cooled binding together the parts with great firmness. Iron, when joined with less expansible materials, as bars laid in masonry, often works serious injury by its expansions and contractions.

**240. Expansion of Liquids.**—If the heat be sufficiently increased it overcomes cohesion, and the solid becomes a liquid. Liquids thus produced by heat, are also expanded by it, and to a

bodies expand equally in all directions, and what unequally? What does Fig. 101 represent? What conclusions follow from this experiment? 239. What illustrations are given of the expansive force of heat? Why are wheel tires made smaller than the wheels they are to surround? How do iron bars work injury in masonry? 240. What

much greater degree than solids. While iron increases from freezing to boiling but $\frac{1}{812}$, water expands $\frac{1}{23}$, and alcohol $\frac{1}{9}$. Hence the seasons materially affect the bulk of spiritous liquors: they measure five per cent. more in summer than in winter. By heating different liquids successively in a long-necked flask, Fig. 8, p. 36, their relative expansibilities are shown.

**241. Expansion of Gases.**—But liquids cannot be indefinitely expanded; a sufficient repulsion of their atoms changes them into gases. As a general law gases expand much more than liquids, although certain liquids, as sulphurous and carbonic acids, are amongst the most expansible bodies known. As there are no varying cohesions to overcome, gases expand very nearly alike, increasing from the freezing to the boiling of water more than one third of their bulk.

**242. Measurement of Heat.**—As the effect of heat is expansion, the measurement of expansion becomes the measurement of the force. The common instruments for measuring heat are called *thermometers*. They measure not quantity of heat, but *temperature*. Heat is the force producing the effect; and temperature the intensity with which it acts. The thermometer gives the same report of a gill of water as of a gallon; their temperatures are the same, though one contains a far larger amount of heat than the other. Liquids are better adapted for thermometers than either solids or gases; as in solids the expansion is too slight to be easily perceptible, and gases are too sensitive to changes of atmospheric pressure to fit them for this purpose.

**243. Mercurial Thermometer.**—To make this instrument, a fine glass tube with a bulb upon the end is partly filled with mercury. The air is expelled from the rest of the tube by heating it till the mercury rises by expansion to the top, and at that moment the glass is hermetically sealed by melting the end of it with a blowpipe. As it cools, the mercury falls in the tube, leaving a vacuum above.

**244.** Mercury has several important advantages as a thermometric fluid. It is readily obtained pure, and does not adhere to the tube; it is sensitive to heat, expands with greater regularity

is said of the expansion of liquids? 241. How do liquids rank in expansibility? Examples. Why do gases expand alike? 242. How is heat measured? What are thermometers? What do thermometers indicate? How are liquids best adapted for thermometers? 243. How is the mercurial thermometer made?

than most liquids, and has a range of 700 degrees between freezing and boiling. Temperatures below the freezing point of mercury are determined by thermometers filled with alcohol tinged with some coloring matter, to make it visible.

Fig. 102.

Common Thermometer.

**245.** The sealed tube is attached to a brass plate engraved with the thermometric scale, Fig. 102. It is then dipped into ice water, and a mark made opposite the top of the column of mercury, called the *freezing point.* It is now introduced into boiling water, and the height to which the column rises is marked as the *boiling point.* These are natural standard points which serve as a basis for the division of the scale. In the *Centigrade* thermometer the freezing point is called zero, and the interval between that and the boiling point is marked off into 100 equal spaces called degrees. In Reaumer's scale the same space is divided into 80 degrees, and in both cases degrees below zero are distinguished from those above by prefixing the minus signs (−).

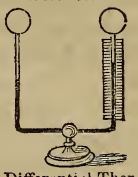
**246.** The scale named after its inventor, Fahrenheit, and which has unfortunately come into general use in England and this country, is not so simple. He divided the space between freezing and boiling into 180 degrees; but, instead of starting at the freezing point, he thought he would find the lowest possible cold, and make *that* zero. So with snow and ice he got the mercury down 32° below the freezing point, and commenced counting there. On this scale, therefore, freezing occurs at 32°, and boiling at 212°. The several scales are distinguished by their initial letters F., C., and R. The Centigrade, affording decimal subdivisions, is the most simple and rational, and is gradually coming into use for scientific purposes. But as Fahrenheit's thermometer is generally employed and most familiar, it will be the one referred to in this book when no other is mentioned.

**247. The Differential Thermometer** consists of two thin glass

244. What advantages has mercury as a thermometric fluid? 245. How are they marked? What is the Centigrade scale? Reaumer's? 246. Describe Fahrenheit's scales. How did he get his zero? What degrees are used in this work? 247. Describe

bulbs filled with air, and united by a bent tube containing a colored liquid, Fig. 103. If heat be applied to one bulb, the air within it expands and presses down the liquid, the degree of motion being shown by the scale. This thermometer, as its name signifies, merely denotes the difference in temperatures between the two bulbs, and has only been useful in scientific researches.

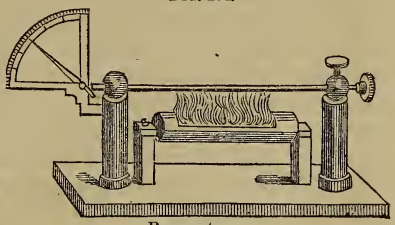
Fig. 103.



Differential Thermometer

248. As mercury boils at 660°, temperatures above that degree are measured by the expansion of solids. For this purpose an instrument called the *Pyrometer* is employed. It consists of a bar of metal or clay, Fig. 104, one end of which is fixed, and the other joined to a lever which plays over a graduated scale, as the bar expands or contracts.

Fig. 104.



Pyrometer.

## § II. *Nature of Heat.*

**249. The Caloric Hypothesis.**—Having noticed the general effects of heat, we may now inquire into its nature. The material hypothesis supposes it to be a kind of matter—a subtile fluid whose entrance into our bodies produces warmth, and its escape cold. This fluid—*caloric*, is supposed to be stored up in the interstices of bodies, some holding more than others, according to their *capacities*. It is assumed to have an attraction for matter and to combine with it, whilst its own particles are self-repulsive, and thus cause the atoms with which they unite to repel each other. This hypothesis, from its simplicity, has done service in times past, but such has been the recent and rapid growth of knowledge, that, instead of any longer guiding to truth, it only eclipses it.

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the differential thermometer? 248. Describe the pyrometer. 249. What is the

**250.** In judging of heat, we must not misinterpret its impressions upon ourselves. If we plunge one hand in ice water and the other in hot water, and then transfer both to water intermediately warm, it will seem hot to the one and cold to the other. Indeed, if we trusted our ordinary sensations, we should believe in two opposite principles of heat and cold, a doctrine which was long advocated until it was found that these are merely relative, and that cold is but the absence of heat. Intense heat and intense cold produce the same sensations; frozen mercury blisters the flesh like hot iron. Putting aside then our sensations, what is it that we know concerning the nature of heat?

**251. The Essence of Heat is Motion.**—With a few exceptions, which are perhaps no real exceptions (485), the universal effect of heat upon all matter is to *expand* it. We say that bodies are heated and cooled, and that one warms another near it. But we strictly mean only that they expand and contract, and that a body in expanding contracts others, and in contracting expands them. Hence, divested of everything not belonging to it, we find the effect of heat to be simply *a motion of expansion in matter* communicable from body to body. Thus the essence of heat is *motion*. The motion of a mass implies the motion of its parts. If a body expands, it is because its atoms have receded farther from each other, that is, have *moved*. Heat is therefore such a motion among the atoms of a body as gives rise to expansion. This idea was clearly enunciated a hundred years ago by the philosopher LOCKE, who said, 'Heat is a very brisk agitation of the insensible parts of an object which produces in us that sensation from which we denominate the object hot, so that what in our sensations is *heat*, in the object is nothing but *motion*.'

**252. Universality of Motion.**—The later views of the forces compel the idea that the atoms of all matter are in a state of incessant movement. As nothing around us is at rest, the idea of the quiescence of atoms would seem to contradict the whole spirit and course of nature. The celestial bodies are in perpetual movement; indeed each one has impressed upon it *several* motions. Our

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material hypothesis of heat? How is it estimated? 250. How may our sensations of heat mislead us? How are heat and cold related? 251. What is the universal effect of heat? When we say that bodies are heated and cooled, what do we strictly mean? What is the essence of heat? What kind of motion? Give LOCKE'S definition of heat. 252. What idea results from the later view of forces? What is

own globe has a motion of rotation upon its axis, lasting a day—a motion of translation round the sun, continuing for a year. It has also one motion upon its axis accomplished in 19 years, and another which is only completed in 25,868 years; it has also a fifth motion with the solar system through space, which may require millions of years for its completion. Thus the character of the solar system depends upon the motions of the planets, which we may look upon as its *atoms*.

**253.** It cannot be doubted that, at the other extreme of being among ultimate atoms, there is also an order of motions equally regular and systematic. Each atom, closely as it seems packed with its neighbors, is believed to be in a state of incessant vibration, and all material bodies, however quiet and solid they appear, are supposed to be made up, nevertheless, of an infinity of these 'whirling parts' which never touch each other and never rest. An atom may rotate upon its axis, oscillate, revolve through an orbit, or, like a planet, it may execute several of these motions at once. This idea has become the all-harmonizing principle of the forces.

**254.** As heat is a motion of atoms, intensity of the motion determines temperature. When a body is heated, the vibration of its atoms is augmented; the particles move through larger spaces; are urged apart, and thus cause the body to expand in bulk. When the vibrations of the atoms of solids become sufficiently violent, they are loosened from the rigid grasp of cohesion, and, continuing to oscillate as before, they are now at liberty to slip or flow around and among each other. This is the liquid state, in which rigidity has disappeared, although a certain amount of lateral cohesion still remains (64). A further augmentation of heat increases the swing of vibration until the atoms are thrown quite beyond the sphere of cohesion, and fly asunder into the vaporous or gaseous state. 'The ideas of the best-informed philosophers are as yet uncertain regarding the exact nature of the motion of heat; but the great point at present is to regard it as a motion *of some kind*, leaving its more precise character to be dealt with in future investigations.'

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probable concerning atoms? What is said of celestial motions? 253. What probability does this create? What view is held concerning the motion of atoms? 254. What results from the intensity of atomic motion? When a body is heated, what occurs within? What results from the violent vibrations of the atoms of solids? What causes the change from the liquid to the vaporous state? What is

**255.** The view just given is known as the *dynamic hypothesis*, or the *mechanical theory* of heat. That branch of the science of thermotics which treats of the laws of heat as a motive power, is known as *thermo-dynamics*. A difficulty in acquiring the new view is, that the current language concerning heat implies the material hypothesis. It is so natural to regard heat as a *thing*—to ascribe a *substantive* existence to that which is the *subject* of a name, that it will be necessary to guard against the misleading tendency of the ordinary terms. The pupil should strive to think of heat not as an abstract thing, but simply as a contagious or communicable motion of atoms. It may be further observed that this hypothesis is far from being new. It has been maintained by the acutest scientific intellects, as those of BACON, BOYLE, NEWTON, MONGOLFIER, SEGUIN, RUMFORD, DAVY, LESLIE, and YOUNG. But the late advances in the knowledge of force have brought it into a new prominence and caused its acceptance by the leading scientific minds of the age. (*See note, page* 173.)

## § III. *Sources of Heat.*

**256.** The chief source of heat is the sun. As the stars are only remoter suns, we undoubtedly obtain from them a large amount of heat; according to POUILLET, almost as much as from the sun itself. Combustion is a familiar source of heat which will be noticed hereafter (579), and the vital heat of animals is due to the same cause (1257). Heat is also produced from the other forces—electricity, magnetism, and mechanical power. To consider the last-named source will aid us to clearer notions of the nature of heat and the true relations of the forces.

**257. The Heat of Friction.**—Nothing is more familiar than the fact that friction produces heat. We warm our hands and ignite matches by *rubbing* them, whilst wood may be set on fire by the friction of one piece against another. The development of heat by friction may be strikingly shown by a simple mechanism. A hollow brass tube is mounted upright upon a table so as to revolve rapidly by turning a wheel. It is closed at the bottom, nearly filled with cold water, and tightly corked. The tube is then clasp-

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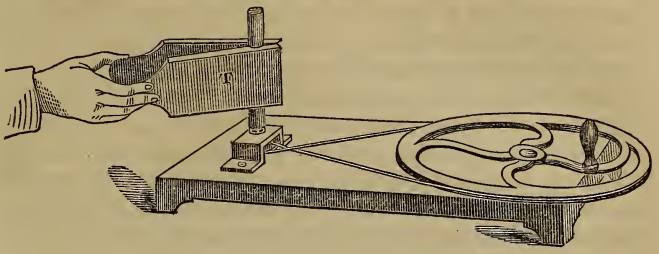
the important point in this connection? 255. What is the view just given called? What is thermo-dynamics? What difficulty is encountered here? What should the student strive to do? Is this hypothesis new? Who have formerly maintained it? How is it now regarded? 256. What are the sources of heat? 257. What

ed in a groove formed by two pieces of oak, T, Fig. 105, joined by

Fig 105.




Machine for converting Mechanical Force into Heat.

a hinge. Upon rapidly turning the wheel, the water is boiled, steam formed, and the cork exploded 20 feet into the air in two minutes and a half. Iron plates ground against each other by water have yielded a large and constant supply of heat for warming the air of a factory in winter. Heat is also produced by the friction of fluids. Rennie inclosed 10 lbs. of water in a box, and, revolving it at the rate of 232 revolutions per minute, in a short time raised it to the boiling point. Hence water running in sluices and the sea after long storms are sensibly warmed.

**258. Compression** also produces heat. A piece of cold wood or a cold leaden bullet squeezed forcibly in a hydraulic press are made warm. *Percussion* is another source of heat. A cold bullet struck upon an anvil by a sledge hammer is heated. A leaden ball lifted several feet and dropped repeatedly, is warmed; and a cannon ball, when striking an iron target or ship's side, is so intense-

Fig. 106.

Mercury warmed by pouring it.

examples are given of the heat of friction? Describe the experiment. 258. Give

ly heated as to produce a flash of light. The arrest of a liquid in motion is also a source of heat. If two glasses are swathed thickly round with listing, so that the warmth of the hand cannot affect them, and then cold mercury is poured from one to the other several times, Fig. 106, its temperature will be raised.

**259.** What now is the source of heat in these cases? The caloric hypothesis utterly fails to explain it. That theory maintains that the heat of friction exists in a latent state in the bodies rubbed; that different substances have different *capacities* for hiding and holding heat, and that friction diminishes this capacity, and thus brings it out, as squeezing brings the water out of a sponge. But this is grossly erroneous, as was proved by DAVY. He rubbed two pieces of ice together in a vacuum, and melted them by pure friction; but the water produced contained a far greater amount of heat than the ice, and the greater quantity could not by possibility be derived from the less. Besides, the amount of heat that various bodies naturally contain, as we shall soon see, is perfectly definite; while, on the contrary, the heat produced by friction *is inexhaustible, and* is utterly independent of the nature of the substance used. This was demonstrated by Count RUMFORD more than sixty years ago.

**260. True Source of the Heat.**—The heat of friction depends not upon the properties of the bodies acting, but upon *the force spent in producing it.* The great principle has been established that force like matter is indestructible. It may be changed from form to form, but can neither be created nor annihilated—the total amount in the universe remains forever the same. Hence when a moving body is stopped, its force is not destroyed, but simply takes another form. When the sledge hammer strikes the leaden bullet and comes to rest, the mechanical force is not annihilated, but is simply converted into heat, and if all the heat produced could be collected, it would be exactly sufficient when reconverted into mechanical force to raise the hammer again to the height from which it fell. So when two bodies are rubbed together, their surface particles are brought into collision, mechanical force is destroyed, and heat appears—the heat of friction.

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examples of compression and percussion. 259. How is this explained by the old hypothesis? What is the bearing of Davy's experiment? Why cannot the heat of friction proceed from the body itself? 260. Upon what does the heat of friction depend? What great principle has been arrived at respecting forces? When a moving

**261.** We place a wheel upon a rough axle and set it to whirling; after a few turns it comes to rest, and the axle is found hot. The mechanical impulse has been converted by friction into heat. We now lubricate the axle with some substance that reduces friction, and set it to revolving again with the same impulse. It now turns a much longer time, and the temperature of the axle is but slightly raised. Yet precisely the same amount of heat is generated in this as in the other case, though the friction is now against the air and the heat escapes without detection.

**262.** Take the familiar case of a railway train. Heat is generated in the locomotive by combustion. A portion of it is wasted, and the remainder is spent in the expansion of water into steam, which through the machinery produces motion of the train. The object is to convert all the heat possible into mechanical motion, and so every rubbing surface is oiled, because each point of friction is so much leakage and loss of motion by reconverting it into heat. But when the train approaches a station where it is desired to stop, what is to be done? The moving force cannot be annihilated; it must be *transformed;* so the brakes are applied, the train slackens, smoke and sparks are produced, and the entire motion of the train is thus converted back again into heat. The rigorous relation of equivalency between heat and mechanical motion will be considered hereafter (411). We only call attention here to the fact that the checking and arrest of mechanical motion, however slight it may be, whether of air, water, or solid bodies, is a definite and universal source of heat; and again that heat, whenever it disappears, invariably produces some form of motion or *work.*

**263.** Now as heat produces mechanical motion, and mechanical motion heat, they must clearly have some common quality. While heat was regarded as material, it was impossible to see anything in common between them, for how could the fall of a body, for instance, be converted into imponderable matter? On the con-

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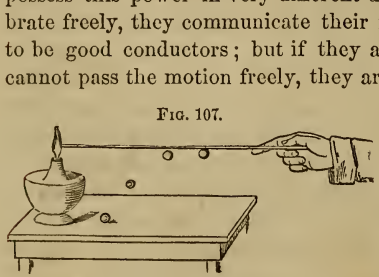
body is stopped, what becomes of its force? How is the case of the sledge hammer explained? When two bodies are rubbed together, what takes place? 261. Explain the experiment with the wheel and axle. What becomes of the heat in the second case? 262. What becomes of the heat in a moving locomotive? What is the effect of the rubbing surfaces? What occurs when the train is stopped? What is the universal relation of mechanical force to heat? 263. How have they a common quality? What is the difficulty here in the material view? What does the mechanical theory affirm? When a moving mass is stopped by friction, what takes

trary, the dynamical theory affirms that as mechanical movement and heat are both modes of motion, they must be mutually and easily convertible. When a moving mass is checked or stopped, its force is not annihilated, but the gross palpable motion is *infinitely subdivided* and communicated to the *atoms* of the body, producing increased vibrations which appear as heat. And so when heat produces work, as in the steam engine, a certain amount of it is destroyed, the motion of the atoms of steam being converted into mechanical motion of the piston and machinery.

## § IV. *Conduction and Convection of Heat.*

**264. How it is Conveyed.**—The closely packed particles of bodies cannot vibrate without communicating their motion from one to another. Each atom takes up the motion of its neighbors and imparts it to others, and thus the effect is gradually propagated through bodies; this is called *conduction* of heat. Bodies possess this power in very different degrees. If the particles vibrate freely, they communicate their motion rapidly, and are said to be good conductors; but if they are so trammelled that they cannot pass the motion freely, they are *bad* conductors.

FIG. 107.



Conduction of Heat.

**265.** If several marbles are stuck by wax to a copper rod, Fig. 107, and heat be applied to one end, it gradually passes along the rod, the wax is melted, and the marbles drop off successively. Generally the more dense a body is, the better it conducts; therefore, solids are better conductors than liquids, and liquids than gases. As a class, metals are the best conductors, but they differ much among themselves in this respect. The imperfect conduction of liquids may be shown by filling a glass tube with water, inclining it over a lamp and applying the flame at the upper end, Fig. 108. The water will boil at the sur-

FIG. 108.

Non-conduction of Liquids.

place? 264. In what way does heat move through bodies? 265. Describe the

face, while at the bottom there may still be ice for a considerable time. Dry air is one of the poorest conductors. Loose materials, as wool, cotton, sawdust, are bad conductors, chiefly owing to the air inclosed in their inner spaces.

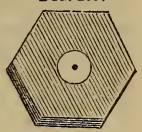
**266. Connection of Heat and Electricity.**—The following table shows the relative conducting properties of several metals, the power declining as the numbers decrease:

| Names of Substances. | Conductibility. For Heat. | For Electricity. |
|---|---|---|
| Silver | 100 | 100 |
| Copper | 74 | 73 |
| Gold | 53 | 59 |
| Iron | 12 | 13 |
| Platinum | 8 | 10 |
| German silver | 6 | 6 |
| Bismuth | 2 | 2 |

The conducting power of the metals for electricity is also given, and a remarkable correspondence is seen in the numbers. Those properties which make a metal a good conductor of heat render it also a good conductor of electricity, and those which obstruct the one obstruct also the other. The forces must also be closely connected in their modes of action.

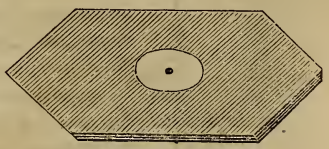
**267. Influence of Atomic Arrangement.**—If the atoms are disposed alike in all directions, conduction is uniform, but, if there is a polar arrangement of atoms, conduction becomes unequal. This is seen in crystals. A slice of quartz cut *across* its axis, Fig. 109, was perforated with a small hole and covered with a layer of white wax. A wire was then inserted through the orifice and heated by an electric current. The wax melted in an exact circle, which showed equal conduction in all directions. A slice cut *parallel* with the axis, as in Fig. 110, treated in the same way, gave an oblong outline of the melted wax, showing that the heat travels with more facility *along* the crystalline axis than across it. The metal bis-

Fig. 109.



Equal Conduction.

Fig. 110.



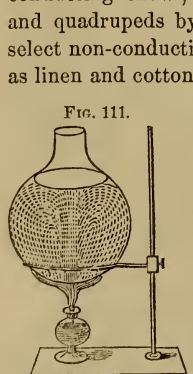
Unequal Conduction.

experiment with the marbles. How is the bad conduction of liquids shown? 266. How does silver differ from bismuth in conducting power? What relation between the conduction of heat and electricity? 267. What condition of atoms

muth conducts both heat and electricity better along the planes of cleavage than across them. The same thing has been found in reference to wood; it transmits heat better along the course of the fibres than across them. This principle economizes the warmth which the tree derives from the soil, by preventing its lateral escape, and at the same time protects the tree from the injurious effects of sudden changes of external temperature. This effect is also heightened by the non-conducting bark.

**268. Conduction Influences Sensation.**—The carpet feels warmer to the naked feet than oil cloth, because the latter conducts away the heat faster from the skin, although both are at the same temperature. If the hand be placed upon silver at 120°, it will be burned, owing to the rapidity with which the motion of heat leaves the metal and enters the flesh. Water will not scald the hand if it be held quietly in it till it reaches 150°, while the contact of air at 250° or 300° may be endured. The principle of conduction is of great importance, not only in nature, but in its application to the arts and requirements of daily life. Nature protects the earth and crops from the excessive cold of winter by a layer of non-conducting snow; the birds she protects by feathery plumage, and quadrupeds by hair, wool, and fur. For winter clothing we select non-conducting textures; but in summer, good conductors, as linen and cotton, to aid the escape of superfluous heat.

FIG. 111.



Circulation of Heat.

**269. Convection.**—Although liquids and gases are poor conductors, yet from the mobility of their particles they may be rapidly heated by a process of circulation or *convection*. If heat be applied to the bottom of a vessel containing water, the lower portion of the liquid is warmed, expands, becomes lighter, and ascends, its place being taken by the colder liquid at the sides—thus forming a set of currents which diffuse the heat through the whole mass. If a few particles of litmus be dropped into a flask of boiling water, the central current, made visible by the blue tint it has acquired, may be seen rising to the surface of the liquid, where it bends over in

influences conduction? What is shown by the experiments with quartz? What of wood? How does this affect trees? 268. How does conduction influence sensation? How is the principle employed in nature? In art? 269. How do liquids

every direction, Fig. 111, and travels down the side of the vessel. In this way, water is circulated through systems of pipes to warm houses.

**270.** Gases are heated in the same manner. The warm air in contact with a stove or other heated body becomes lighter, and ascends, while the colder and heavier air rushes in to supply its place. This, becoming heated, also ascends, and thus a system of currents is established which diffuses warmth through the apartment. This principle is applied in warming houses with hot air, and also in arrangements for artificial ventilation. In the ocean and the atmosphere the same exchanges are incessantly going on, in the former giving rise to vast currents which equalize its temperature, and on land producing breezes, storms, trade winds, &c.

## § V. *Latent Heat—Interior Work.*

**271.** Heat, by overcoming the cohesion of solids, detaches their atoms and changes them into liquids. That degree of heat which is required to liquefy a substance is called its *melting point.* From hundreds of degrees below zero up to thousands above, the various substances of nature melt at different temperatures, showing that each requires its particular amount of heat force to throw it into the liquid state.

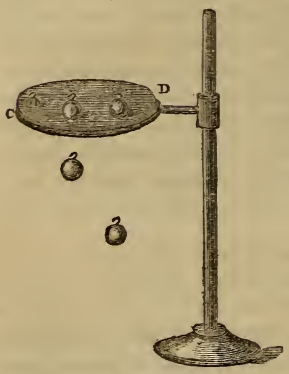
**272. Latent Heat.**—Whenever a solid is changed to a liquid, a certain amount of thermal force disappears in the process. If we apply heat to a lump of ice at 32°, it gradually melts, but the water produced is at the same temperature as the ice. What then has become of the heat? In the language of the old hypothesis, the disappearing caloric is stored up in the water, where it still exists in a state of concealment as 'latent' heat. But there is no evidence that it *continues to exist as heat.* According to the dynamic view, the heat *does work* by overcoming the cohesion of the particles, and is consumed in forcing them into new relations. This theory maintains that force cannot disappear without producing some effect; it teaches that what is called 'latent' heat is simply that amount of thermal force which is consumed in pro-

convey heat? Describe the experiment. 270. How are gases heated? 271. Explain melting points. 272. According to the old view, what becomes of the heat when ice is melted? What evidence is there that it still exists as heat? What is

ducing effects *different from heat*, as fusion, evaporation, chemical changes, &c.

**273.** If we expose equal weights of different substances to the same source of heat, they do not all receive it with equal readiness or in equal amounts in the same length of time; some will become much warmer than others. If a cake of wax, C D, Fig. 112, be placed upon the ring of a retort stand, and several metallic balls, having been immersed in a bath of hot oil, be placed upon it, they will sink through the wax at different rates. The iron gets through first, and the copper follows. The tin ball just peers through the lower surface, and is stopped, while the lead and bismuth scarcely sink to half the depth of the cake. Although the balls are all at the same temperature, yet they hold very unequal amounts of heat. Water requires 30 times as much heat as mercury to raise an equal weight of it through the same number of degrees. Hence bodies are said to have different *capacities* for heat, and, as each substance seems to require a particular quantity for itself, that quantity is called its *specific* heat.

FIG. 112.




Hot Metallic Balls.

**274. Calorimetry** is the art of measuring the specific heat of bodies. This may be done in various ways: one is by observing the quantity of ice which equal weights of different substances melt in falling through equal degrees of temperature. The specific heat of water is found to be the highest of any known substance. Water being taken as 1, sulphur is 0.20, air 0.25, iron 0.11, copper 0.09, and lead, mercury, and gold, 0.03.

**275. Twofold Action of Heat.**—Thus when heat falls upon a body, a portion of it is manifested by the rising temperature, and is spent in producing increased vibrations of the atoms. But another portion is spent in forcing the particles of bodies into new posi-

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the dynamic view? How does it regard latent heat? 273. Describe the experiment of the cake of wax. What does this prove? What is capacity for heat? Specific heat? 274. What is calorimetry? 275. When heat falls upon a body, what becomes

tions, and as different substances have different atomic constitutions, different amounts of heat are consumed in acting upon them —these amounts are their *specific* heats.

**276.** It has been well suggested that the atoms drawn together by cohesion resemble a weight pressed to the earth by gravity. With a cord and pulley we can overcome the gravity and raise the weight; and we can also cause it to oscillate as it rises. *One* portion of the force is expended in raising it from the ground, and *another* in causing its vibrations. So with the atoms: at the same time that their vibrations are increased they are also forced into new arrangements. Heat consumed in this latter way is said to perform *interior work*. As the body cools, the constrained atoms gradually resume their former places, and the precise amount of heat is given out again.

**277. Potential and Actual Energy.**—When a weight is drawn up by a cord, it may be perfectly at rest, but the new position makes it a *store of force*, which in its fall becomes *moving* force. While suspended it was said to be in a state of possible or *potential* energy; in falling, this is converted into *actual* energy. When it has fallen part of the distance, it is evident that a certain amount of potential energy is converted into actual energy; and, as it strikes the earth, *all* its potential energy is converted into actual energy. 'As potential energy disappears, actual energy comes into play; *throughout the universe, the sum of these two energies is constant.*'

**278.** This principle applies equally to atoms; the weight and the earth may represent two mutually attracted particles. The atoms of wood and coal are in the raised condition of *potential energy;* oxygen may represent the earth; they rush together in the furnace, and their potential energy is converted into the actual energy of heat. This again is spent in raising the atoms of water to the potential energy of steam. Again, the atoms of steam fall, and their potential energy is converted into the actual energy of the moving engine.

**279. Tremendous Energy of Atomic Movements.**—As our or-

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of it? 276. What do atoms attracted together resemble? How are the twofold motions illustrated? What is interior work? 277. How does a weight suspended differ from one upon the ground? What is potential energy? Actual energy? Their relation? 278. What is the condition of the atoms of wood and coal? How do they produce the actual energy of heat? What becomes of the heat? 279. How are we too apt to regard interior work? What is the most impressive lesson of

dinary conceptions of force result from the large effects that strike the senses, we very naturally conclude that the interior work performed by heat among insensible atoms is but a trifling affair; but this is a grave mistake. The most impressive lesson of modern science is, that the material objects around us which appear so passive are, nevertheless, filled with the most TREMENDOUS ACTIVITIES. A pound of iron upon being heated from freezing to boiling expands $\frac{1}{500}$ of its length. The atoms are but slightly shifted, yet the heat necessary to move them would raise 8 tons one foot high; or, in other words, the heat exerts a force upon the iron 16,000 times greater than that of gravity.

**280.** In melting 9 lbs. of ice, heat changes the position of the atoms, and confers upon them the *potential energy* of water. Additional heat drives the atoms further asunder, and confers upon them the higher potential energy of steam. Still further heat (or an equivalent force) decomposes the steam, forming 1 lb. of hydrogen gas and 8 lbs. of oxygen gas, with a still higher state of potential energy. Now, in returning to their former conditions, they give out an actual energy exactly equal to their potential energy. The clashing force of the atoms, as they revert to the successive states, has been represented by the fall of a weight down three great precipices. The first fall—the collision of the two gases—is equal to the plunge of a ton weight down a precipice 22,320 feet high; the second fall—the condensation of the steam—is equal to the descent of a ton down a precipice 2,900 feet high; and the third, the freezing of the water, is equal to the fall of a ton weight down a precipice 423 feet high.

**281.** Prof. TYNDALL remarks, 'I have seen the wild stone avalanches of the Alps, which smoke and thunder down the declivities with a vehemence almost sufficient to stun the observer. I have also seen snowflakes descending so softly as not to hurt the fragile spangles of which they were composed; yet to produce from aqueous vapor a quantity of that tender material which a child could carry, demands an exertion of energy competent to gather up the shattered blocks of the largest stone avalanche I have ever seen, and pitch them to twice the height from which they fell.'

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modern science? What are the comparative effects of heat and gravity upon a pound of iron? 280. What changes does heat work in nine pounds of water? What are the steps of potential energy which the atoms ascend? To what is their actual energy equal? 281. What striking illustration does Prof. TYNDALL give of the

## § VI. *Liquefaction—Freezing—Ebullition.*

**282.** The amount of force consumed in producing liquefaction is readily ascertained. If we take an ounce of ice at 32°, and one of water at 174°, and put them together, when the ice is melted, we shall have two ounces of water at 32°. The ounce of hot water has therefore parted with 142° of its heat in melting the ice, which amount is the 'latent heat' of the resulting water. Those who have attempted to melt snow for domestic purposes know by the delay in the result the great loss of heat involved.

**283.** We here note the beneficial influence of thermal laws in the world's economy. If when ice is at 32°, the addition of one degree of heat would raise it to 33°, and thus throw it into the liquid form, all the accumulated snows of winter might be turned almost in an hour into floods of water, by which whole countries would be inundated. But so large an amount of heat is required to produce this change, that time must become an element of the process; the snows are melted gradually in spring, and all evil consequences are prevented.

**284. Freezing Mixtures.**—Advantage is taken of the absorption of heat in liquefaction to produce freezing mixtures, the most common example of which is salt and ice. In this case the salt melts the ice to unite with its water, which in turn dissolves the salt, so that both solids are changed to liquids. These changes require great heat, which is absorbed from surrounding bodies; the cold produced sinking the thermometer 40° below zero. Four ounces each of sal ammoniac and nitre finely powdered, and mixed with eight ounces of water, will reduce the temperature from 50° to 10°. A convenient method of freezing a little water is to drench powdered sulphate of soda (Glauber's salt) with muriatic acid; it may sink the thermometer from 50° to zero.

**285. Heat Liberated by Freezing.**—If the change of a solid to a liquid *consumes* force, the reverse change must *produce it;* the force therefore reappears as heat upon freezing. As the thawing of snow and ice in spring is delayed by the large amount of heat that is expended in the forming of water, so the freezing processes

power of molecular forces? 282. How is the heat of liquefaction found? 283. What are the effects of this principle? 284. How do snow and ice produce cold? Mention another freezing mixture. 285. How is freezing a warming process? Its

of autumn are delayed, and the warm season prolonged, by the large quantities of heat that escape into the air, from the changing of water into ice. The same principle is made available to prevent the freezing of vegetables, fruits, &c., in cellars, during intensely cold weather. Vessels of water are introduced, which, in freezing, give out sufficient heat to raise the temperature of the room several degrees: freezing is thus made a means of warming.

286. **Regelation.**—Attention has lately been called to the fact that if pieces of moistened ice are brought into contact, they freeze together; lumps swimming in water—even *warm* water—may be made to cohere. This phenomenon is called *regelation*. The surface particles of the ice gain their liquid freedom, because they are confined only on one side, but when the surfaces are brought together, this liberty is instantly checked; what was the surface becomes the centre, and cohesion takes place. Ice crushed to fragments can be refrozen in a few seconds under hydraulic pressure into a solid transparent mass, taking the shape of the mould in which it is pressed. It has long been a matter of inquiry by what property of ice those frozen rivers, the *glaciers*, slowly move along their tortuous beds, down the sides of mountains. It has been attributed to a viscous property by which the ice flows like thick tar; but regelation—the property of crushing and freezing under pressure—seems better adequate to explain the facts.

287. **Ebullition.**—When water is gradually heated, minute bubbles are found at the bottom of the vessel, which rise a little way, are crushed in, and disappear. These consist of vapor or steam, which is formed in the hottest part of the vessel, but as they rise through the colder water above, are cooled and condensed. The singing sound of vessels upon the fire just before boiling is supposed to be caused by vibratory movements produced in the liquid by the formation and collapse of these vapor bubbles. As the heating continues, these rise higher and higher until they reach the surface and escape into the air, producing that agitation of the liquid which is called *boiling* or *ebullition*.

288. The temperature at which this takes place is called the *boiling point*. Different liquids boil at different temperatures, but

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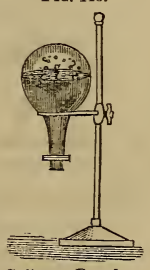
effect in nature? 286. What is regelation? How are glacial motions explained? 287. What is the cause of boiling? 288. What is the boiling point? What causes its

each liquid has a boiling point peculiar to itself. This varies with circumstances; it is slightly influenced by the nature of the containing vessel. To glass and polished metallic surfaces liquids adhere with greater force than to rough surfaces; and before vaporization can occur, this adhesion must be overcome. Substances dissolved in a liquid also raise its boiling point on account of their adhesion. Under ordinary circumstances, water boils at 212°, but saturated with common salt its boiling point is 224°. It has lately been shown that the amount of air dissolved in the water affects its boiling point, as it presses the watery particles asunder, and thus aids them to take on the gaseous state. Water purged of its air by long ebullition has been heated to 275° without boiling. When it did boil the water was instantly changed into vapor with a loud explosion, the cohesion of its particles being suddenly overcome, like the snapping of a spring, by the repulsive power of the accumulated heat. The explosion of steamboat boilers, it is thought, may sometimes be owing to this cause.

**289.** But the most important circumstance that influences the boiling point is the pressure of the atmosphere. This resists the rising vapor, and as it fluctuates, the boiling point varies. At the level of the sea, atmospheric pressure is about 15 pounds upon every square inch of surface, and its variations make a difference of 4½ degrees in the boiling point. This pressure becomes lighter as we ascend into the atmosphere, and the temperature of the boiling point is correspondingly diminished, so that boiling water is less hot in high altitudes than in low ones. At the hospital of San Bernard on the Swiss Alps, which is 8,400 feet above the sea, water boils at 184°.

Fig. 113.



Culinary Paradox.

**290. The Culinary Paradox** affords a striking illustration of the boiling of water at a low temperature under diminished pressure. A flask half filled with boiling water is tightly corked and inverted upon the ring of a filter stand, Fig. 113. The pressure of the confined steam will cause the boiling instantly to cease. If *cold* water be now poured upon the flask, the steam

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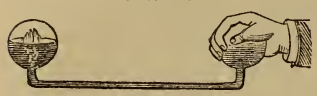
variation? What is the effect of removing air from water? 289. How does pressure affect the boiling point? How ascending a mountain? 290. What is the

within will be condensed, the pressure relieved, and boiling will commence energetically. If again hot water be poured upon it, by renewing the steam and the pressure, the boiling ceases. The *pulse glass* is a tube connecting two bulbs, and half filled with ether, air being excluded. On grasping one of the bulbs, the heat of the hand so expands the ether, that its vapor forces the liquid into the other bulb with violent ebullition, Fig. 114.

Fig. 114.



Pulse Glass.

**291. The Spheroidal State.**— Water adheres to most surfaces, but heat destroys this attraction, and, if drops of it fall upon a red-hot plate of metal, they gather into spheroids, roll about, and evaporate very slowly. Fig. 115 represents a mass of water in the *spheroidal state.* In this case the heat of the metal produces a layer of vapor which supports the drop, so that it does not touch the surface, but is driven about by a current of heated air. The temperature of the spheroid never reaches the boiling point of the liquid, as the vapor, being a non-conductor, does not transmit the heat from the metal, and besides, it is kept cool by evaporation from its surface. If the temperature of the plate be allowed to fall to a point at which the water wets its surface, it will be suddenly scattered in a kind of explosive ebullition, Fig. 116.

Fig. 115.

Spheroid of Water.

Fig. 116.

Its Explosion.

**292.** All volatile liquids act in this respect like water. Liquid sulphurous acid, when poured into a red-hot crucible, takes the spheroidal state, and, as its boiling point is 18° below the freezing point of water, we can actually freeze water by pouring it into sulphurous acid in a red-hot crucible. We can thus explain another remarkable fact. If damp with perspiration, or slightly moistened, the hand may for an instant be dipped in melted lead, or white-hot melted iron, without burning or discomfort. The thin film of

culinary paradox? The pulse glass? 291. What is the spheroidal state? How is the spheroid supported? Why does it not boil? Why does it explode? 292. How may water be frozen in a red-hot crucible? What facts does this explain?

moisture is thrown into the spheroidal condition, and presents an effectual barrier against the intense heat.

## § VII. *Vaporization.*

**293.** The change of solids or liquids by the force of heat to vapor is called *vaporization.* Substances which are readily converted into vapor are said to be *volatile*, while those which are vaporized with difficulty are termed fixed or *non-volatile.* The slow formation of vapor from the surfaces of bodies is called *evaporation.* It goes on at all temperatures, even from the surface of ice and snow, but is rapidly increased as the temperature rises.

**294. Heat of Vaporization.**—A much larger amount of heat is spent in converting liquids into vapors than in changing solids to liquids, while the vapors are no hotter than the liquids from which they are formed. The heat has been consumed in producing the repulsive motion and the consequent enormous expansion of the gaseous body. If the liquid is exposed to the air, it is impossible to raise its temperature above its natural boiling point. All the heat added after boiling commences is carried away by the vapor. Water boiling violently is not a particle hotter than that which boils moderately.

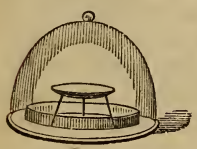
**295.** The quantity of heat which disappears during evaporation is very large. With the same intensity it takes $5\frac{1}{2}$ times as long to evaporate a pound of water as it does to raise it from freezing to boiling; it hence receives $5\frac{1}{2}$ times as much heat. If therefore 180° were required to boil the pound of water, nearly 1,000° are necessary to change it to vapor, and being spent in producing the change of state, it of course disappears. This quantity is, therefore, the 'latent' heat of steam. If the process be reversed and the vapor be made to reassume the liquid form, the heat reappears. The condensation of a pound of steam will raise $5\frac{1}{2}$ pounds of water from the freezing to the boiling point. Steam is hence a valuable agent for transporting heat, as is done by steam pipes for warming buildings.

**296. Its Cooling Effects.**—As evaporation consumes heat, it is

293. What is vaporization? Evaporation? 294. What is said of the heat required? How is it consumed? Why does not boiling water grow hotter? 295. How much heat is required to vaporize a pound of water? What is the latent heat of steam? If the steam is condensed, what follows? 296. Mention some of the cooling effects

a cooling process. We experience this in the cold sensation of evaporating a few drops of ether from the hand. As the perspiration evaporates from the skin, it becomes a powerful cooling agency and regulator of bodily temperature, while the vapor which escapes from the breath, by its absorption of heat, exerts a cooling effect within the body. It is interesting to observe how the great capacity of water for heat makes it so gratefully cooling as it enters the body, and how its still greater capacity for heat when passing into vapor enables it so constantly to bear away from us the germs of fever as it escapes from the system in the form of insensible or manifest perspiration. The pernicious effect of wearing wet clothing arises from the rapid evaporation of its moisture, which robs the body of large quantities of heat. Damp soils are cooler than dry ones, because evaporation dissipates the heat which falls upon them. The heat of torrid regions would be insufferable, were it not for the cooling effects of rapid evaporation. Wind hastens evaporation, as it carries away the air as soon as it is laden with moisture, replacing it with drier air.

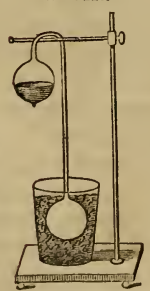
FIG. 117.



Freezing Water.

**297. Freezing by Evaporation.**—Water may be frozen by its own evaporation, as may be seen in the experiment, Fig. 117. A vessel of water and another of sulphuric acid are placed under a bell jar from which the air is exhausted. The sulphuric acid absorbs the moisture of the water so rapidly that the latter is soon frozen.

FIG. 118.



The Cryophorus.

**298. The Cryophorus or Frost Bearer** is an instrument which strikingly illustrates this principle. It consists of a tube with a glass bulb at each extremity, one of which contains a little water. Air is expelled from the instrument by boiling the water, the aperture through which the steam escapes being sealed, while the remaining space is filled with vapor. The empty bulb is then placed in a freezing mixture, Fig. 118, and the vapor condenses, its place being

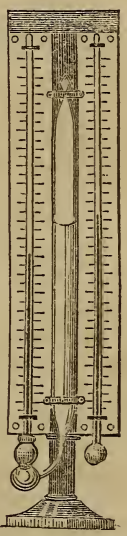
of evaporation. Why is wet clothing injurious? 297. How may water be frozen by evaporation? 298. Explain the principle of the cryophorus. 299. How and by

supplied by vapor from the water bulb. Condensation and evaporation go on so rapidly that the water is soon frozen.

**299.** The greatest artificial cold has been produced by the rapid evaporation of highly volatile liquids. By the vaporization of carbonic acid and ether in the vacuum of an air pump, FARADAY reached 166° below zero, while, by mixing liquid protoxide of nitrogen with bisulphide of carbon in a vacuum, M. NATTERER produced the lowest recorded temperature, 220° below zero.

**300. Moisture in the Air.**—The air always contains moisture, the amount of which varies with the temperature. The power of the air to absorb moisture is called its *capacity for absorption.* When it contains as much as it is capable of holding at a given temperature, it is said to be *saturated*, and any lowering of the temperature condenses it in the form of clouds, mist, fogs, dew, &c. The degree of temperature at which the moisture is condensed is called the *dew point.* If the temperature of the air has to fall but a few degrees before moisture is deposited, the dew point is said to be *high*, and there is much moisture in the air; while, if the temperature must fall far, the dew point is low, and the air contains less moisture. It is obvious, therefore, that, by finding these two points of temperature, one can easily obtain the amount of atmospheric humidity.

FIG. 119.



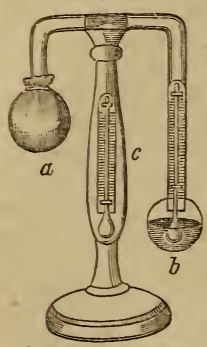
Wet Bulb Hygrometer.

**301. Hygrometers** are instruments for measuring atmospheric moisture. The one most generally used is the *wet bulb* hygrometer, Fig. 119, and consists of two thermometers, one of which shows the temperature of the air. The bulb of the other is covered with muslin, which is kept constantly moist by a string leading from it to a reservoir of water below. Evaporation takes place from the moistened bulb at a rate which depends upon the dryness of the

whom have the lowest degrees of cold been found? 300. Upon what does the amount of moisture in the air depend? What is the effect of lowering its temperature? What is the dew point? Meaning of high and low dew points? 301. What are hygrometers? Explain the principle of the wet bulb hygrometer. 302. Of

air; and by the coldness thus produced the mercury in the thermometer is correspondingly depressed. By comparing the difference between the two thermometers at any time, and referring to a table, the quantity of moisture in the atmosphere is ascertained.

FIG. 120.




Daniell's Hygrometer.

**302. Daniell's Hygrometer,** Fig. 120, is a beautiful instrument for determining the dew point, constructed on the principle of the cryophorus. The long limb ends in a glass bulb *b* half filled with ether, into which dips a small thermometer. The bulb *a* on the short limb is empty and covered with muslin. The temperature of the air is shown by another thermometer, *c*, affixed to the stand of the instrument. When an observation is to be made, a little ether is poured upon the muslin, and, as it evaporates, the temperature of the other bulb becomes reduced. When it is sufficiently cold to condense the moisture of the air, it will be covered with dew. The thermometer in the tube *b* shows at what temperature this deposition takes place, and of course gives the dew point. This instrument is more accurate than the former. The amount of moisture in the air of our artificially heated rooms is a matter of great importance to health, and the hygrometer is very valuable in enabling us to determine it.

**303. Volume and Density of Vapor.**—Equal bulks of different liquids generate unequal volumes of vapor. Water yields a larger amount than any other liquid. While a cubic inch of water gives 1,694 inches of vapor, a cubic inch of alcohol yields 528, one of ether 298, and of oil of turpentine 193. But the less the volume of vapor, of course the greater its density. While 46.6 cubic inches of turpentine vapor weigh 68 grains, the same bulk of ether weighs 37, of alcohol 23, and of watery vapor but 9 grains. The density of vapor is increased, either by cold or pressure. The point at which its temperature cannot be further lowered without returning to the liquid state, is called its *maximum density.*

**304. Its Elastic Force.**—All vapors are elastic, and have a

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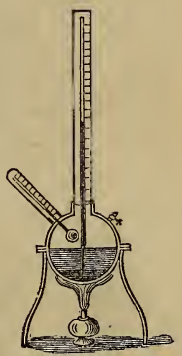
DANIELL'S hygrometer? 303. How much vapor is produced by a cubic inch of water? Of alcohol? Ether? Oil of turpentine? How do their densities compare? What is the maximum density of vapor? 304. What is the elastic force of

tendency to diffuse themselves through space, exerting more or less force against any obstacle that resists their expansion. This expansive force of vapors is called their *elastic force* or *tension*. In the barometer, a column of mercury 30 inches high is driven into the tube by the pressure of the air (563). It, therefore, requires a force of 15 lbs. per square inch to press the mercury all out of the tube. If a little water be introduced under the bottom of such a tube, it rises to the surface of the mercury, and in the vacuum above exhales into vapor with a sufficient force to press the mercury down below its former level. But the amount of this elastic force depends upon the temperature. At 36° below freezing, although the water is changed to ice, it still gives off a vapor of force sufficient to depress the mercury $\frac{1}{20}$ of an inch; at 36° it sinks it $\frac{1}{5}$ of an inch; at 80°, 1 inch; at 179°, 15 inches; and at 212° the mercury is pressed entirely out of the tube, proving that the elastic force of the vapor at 212° or boiling point equals the atmospheric pressure. Different vapors have different degrees of elastic force. At 80° the vapor of alcohol depresses the column 2 inches, and that of ether 20 inches.

Fig. 121.



Marcet's Digester.

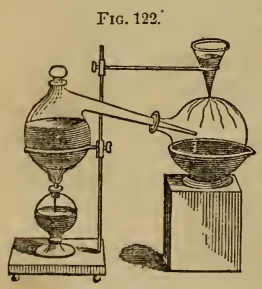
**305.** As the temperature rises above 212°, the elastic force increases, and the boiling point becomes higher and higher, as is proved by an apparatus called 'Marcet's Digester,' Fig. 121. This consists of a small globe of iron or brass, with three apertures, through one of which a thermometer is passed, air tight; through the second, a long glass tube, open at both ends, and reaching nearly to the bottom of the vessel; while the third is furnished with a stopcock. To the tube is attached a scale divided into inches. Mercury is now poured in, sufficient to cover the end of the tube, and the globe is half filled with water, in which the thermometer bulb is immersed. Upon applying heat with the *stopcock open*, the water boils at 212°, and the steam is driven out against the pressure of the atmosphere. But if the stopcock be closed, the temperature begins to rise; the steam being confined, its tension increases, and the

vapor? How may it be ascertained? 305. What are the parts of MARCET'S apparatus? What takes place when heat is applied with the stopcock open? With it

mercury begins to be pressed up the tube. At 249.5° the mercury will have been driven up 30 inches, and the pressure is equal to an additional atmosphere; at 356.6° it is equal to 10 atmospheres, and at 415.4° it is equal to 20.

**305. Steam.**—It is well known that the expansive force of heat, acting through the vapor of water, is the impelling power of the steam engine. In low-pressure engines, steam is used from below the pressure of the atmosphere up to 20 or 30 lbs. per square inch above it, while high-pressure engines employ steam of 70 or 80 lbs. pressure to the inch. It has been noticed that gases expand equally by equal additions of heat, the proportion being about $\frac{1}{480}$ part of their volume with each degree of temperature. But with steam *in contact with water* and constantly generated, it is not the case. With equal additions of heat, the expansion is more rapid at high temperatures than at low ones; hence there is an economy of force in using high-pressure steam. With low pressure there is an economy of heat and fuel, but, as the steam, instead of being driven out, is condensed into water, the necessary apparatus renders the engine complicated and cumbrous. Steam separated from water expands uniformly like gases, and may part with its additional heat without being condensed. When it is thus separated, and receives an extra charge of heat, it is said to be *superheated*. At high temperatures, it is used to carbonize wood and disorganize animal matter, which it does, by reducing the flesh to a fluid mass, the bones being separated in a state of powder. It may be heated sufficiently hot to melt lead.

FIG. 122.



Distillation.

**307. Distillation** consists in vaporizing a liquid by heat in one vessel, and condensing it by cold in another, Fig. 122. The object may be either to separate a liquid from non-volatile substances dissolved in it, as in distilling water, to purify it from foreign ingredients, or to separate two liquids which evaporate at different temperatures, as alcohol and water. In the latter case, the

closed? 306. What steam pressures do different engines employ? How is high-pressure steam economical? What are the advantages and disadvantages of low-pressure engines? What is superheated steam? What is it used for? 307. What

heat is carried just high enough to vaporize the most volatile liquid. The product of the process is called the *distillate*. When solids are vaporized, the process is termed *sublimation*, and the condensed vapor a *sublimate*.

**308. Condensation of Gases.**—When a gas loses heat enough to change it to a liquid or solid state, it is said to be *condensed*. The distinction between gases and vapors was formerly supposed to be that the latter are condensible into liquids, while the former are not. But under the joint influence of pressure and extreme cold, many gases once considered permanent have been reduced to liquids, and some even to the solid state. Dr. FARADAY effected this by a very simple method. He placed the materials from which the gas was to be generated in one end of a glass tube bent in the middle, which was then hermetically sealed, Fig. 123. The expanding gas confined in so small a space exerted a tremendous pressure, the force of which condensed a portion of it into a liquid in the other end of the tube, which was immersed in a freezing mixture to facilitate the process. By this method, and at a temperature of – 166°, he succeeded in liquefying carbonic acid, chlorine, ammonia, and several other gases. More recently M. NATTERER, of Vienna, applied a cold of – 220° and a pressure of 3,000 atmospheres; but some of the gases, as oxygen, hydrogen, nitrogen, carbonic oxide, refused to liquefy, even under this tremendous force. It is supposed, however, that, under the proper conditions of cold and pressure, all gases could be made to assume the liquid or the solid state.

FIG. 123.

Condensation Tube.

**309. Radiant Heat** is a branch of thermotics usually treated in this connection; but it is a mode of action so closely linked with light, that we shall obtain a clearer view of its nature by considering them together. This will be especially proper, as a chief purpose in treating of the forces is to bring out the idea of their intimate connections and correlations.

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is distillation? Its object? What is sublimation? 308. What was the former distinction between vapors and gases? Does it still hold? How did Dr. FARADAY effect the condensation of gases? How far has M. NATTERER gone with these experiments. 309. Why is radiant heat deferred? 310. What is the common

# CHAPTER V.

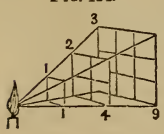
## LIGHT—THE RADIANT FORCES.

### § I. *Movements of Light.*

**310.** In its common, restricted meaning, light is that agent which, acting on the eye, produces vision, and the general laws of its movement belong to optics. But science has shown that the solar ray, instead of being simple, is a sheaf of diverse forces which produce the most extensive and varied changes, physical and chemical, upon the surface of the earth. These effects, though of different kinds and differently named, are all due to one mode of action; they have a common explanation, and hence require to be considered *together*. Light is called a *radiant* force, because it moves in *rays;* other forces, moving in the same manner, are also called *radiants* or *radiations*.

**311. Decrease of Intensity.**—Light moves in straight lines, and in all directions from the point of emission. As it radiates away, it diminishes in intensity as the square of the distance from the point of emission; that is, at a distance of two feet the light will be four times less intense than at one foot; at three feet it has but one ninth the intensity, as shown in Fig. 124, where the upper figures represent the distances, and the lower ones the corresponding intensities. It has been proved in various ways that this force moves through space with the velocity of 192,000 miles per second.

Fig. 124.




Decreasing Intensity.

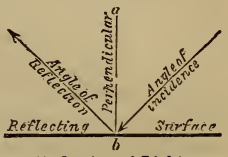
**312. How Light is Received.**—When it falls upon bodies, it is either thrown back from them (*reflected*), extinguished by them (*absorbed*), or passed through them (*transmitted*). Those which transmit it, as air and water, are termed *transparent;* those which admit it only partially, as rough glass, or oiled paper, are called *translucent*, while those which refuse to transmit it are said to be *opaque*. We can see *objects* through a transparent substance, but

notion of light? How is it regarded by Science? To what are the effects due? What are radiant forces? 311. At what rate does light diminish in intensity? What is its velocity? 312. How do bodies receive light? What is transparency?

only *light* through a translucent one. The body traversed by light is called a *medium.* No medium is perfectly transparent; even the purest air absorbs a portion of the light in its passage through it. Nor are any substances absolutely opaque; even gold in thin films transmits a greenish light.

**313. Reflection.**—When a ray of light strikes perpendicularly, or at right angles upon a polished surface, as at *a b*, Fig. 125, it is thrown back in exactly the same line; but if it fall obliquely, it is reflected obliquely, as is shown by the arrows. The angle of rebound is equal to the angle of striking, or, as it is commonly expressed, the angle of reflection is equal to the angle of incidence.

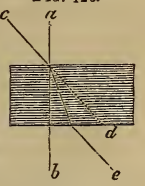
Fig. 125.




Reflection of Light.

**314. Refraction.**—When light passes from one medium to another of a different density, as from air to water, it is liable to be turned out of its straight direction. If its course be perpendicular, as *a b*, Fig. 126, it will not be diverted; but if it fall obliquely, as at *c d*, it will be *refracted*, and proceed to *e*. If the refracting medium have parallel surfaces, the ray on leaving it is again bent back to its original course, as is seen in the figure. For this reason, common window panes, which consist of plates of glass with parallel surfaces, produce no distortion in the appearance of objects seen through them. If we partly immerse a stick in water, it will seem bent or broken at the point of entrance, owing to the rays from the immersed portion being refracted as they pass from the water to the air. The refracting power varies in different substances, generally increasing with their density. It, therefore, forms one of the distinguishing properties of bodies, and is frequently used as a test of chemical purity, as in detecting the adulteration of essential oils, when other modes would prove insufficient.

Fig. 126.




Refraction.

**315. The Analysis of Light.**—By the *prism*—a triangular piece of glass, or other transparent substance—the sheaf of rays is un-

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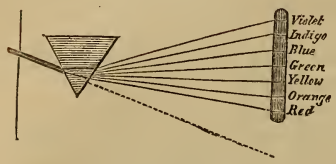
Translucency? Opacity? A medium? 313. By what law is light reflected? 314. What is refraction? What causes the broken appearance of an oar in water? 315. How is light affected by the prism? What is the spectrum? What is the

bound, and spread out before us. A beam of solar light passing through such a prism, Fig. 127, is refracted by it, and produces an oblong colored image called the *solar spectrum*. It is usually considered to comprise the seven colors enumerated in the accompanying diagram. White light is, therefore, held to be a compound consisting of these colored lights, which are only *separated* by the prism.

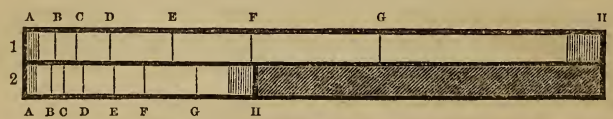
FIG. 127.




Decomposition of Light.

Each color has its own peculiar refrangibility, or degree of divergence from the original source, the *red* being least refracted, and the *violet* most. The separation of the colors in the spectrum is called *dispersion*, and transparent substances differ much in this power. A hollow glass prism filled with oil of cassia gives a spectrum (1), Fig. 128, more than twice the length of that produced by flint glass (2).

FIG. 128.




1. Spectrum from prism of oil of cassia. 2. From flint glass.

The letters correspond to certain fine dark lines which cross the spectrum and serve as its permanent landmarks. These lines are hence more separated in the highly dispersed spectrum (1) than in (2.)

**316.** The separate colors cannot be again decomposed; hence they are called *primary*. NEWTON, who first decomposed the ray, assumed that there are seven; BREWSTER holds to three primaries—red, yellow, and blue, the remaining colors being compounded of these. HERSCHEL says any three colors of the spectrum may be taken as primary, and all the others compounded from them by the addition of white; while Prof. BADEN POWELL remarks, 'The fact is, the number of primary rays is not really seven, but infinite.'

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separation of colors in the spectrum called? What is the effect of the oil-of-cassia prism? 316. Why are the colors called primary? What was NEWTON'S view of the constitution of the spectrum? BREWSTER'S? HERSCHEL'S? BADEN POWELL'S?

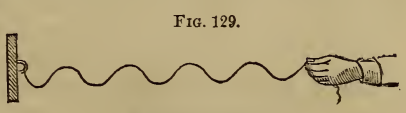
## § II. *The Wave Theory.*

**317.** The old hypothesis of light assumed it to consist of moving particles, or corpuscles, shot from the luminous source, which pass through transparent bodies, rebound from reflecting surfaces, and entering the eye, produce vision by striking against the optic nerve. But the luminous ray produces a variety of effects—heat and chemical force as well as light, with various kinds and gradations of each, and the foregoing explanation is profoundly insufficient to account for all these complex and wonderful phenomena. Evidently there is but one principle of action among all the forces of the ray: the key to light and color must also unlock the mystery of the thermal and chemical radiations. We have this explanation in the *wave theory* of light.

**318. Motion of Sound.**—Sound is a radiation; it proceeds rapidly in straight lines in all directions from the point of emission; is reflected and refracted according to the same laws which govern the other radiant forces, and may be passed through lenses and conveyed to focal points like light. But sound is proved to be a motion of waves or undulations transmitted through the air. Here then is a principle of nature employed to produce the kinds of effect with which we are dealing.

**319. Wave Motions.**—With these we are all familiar. If one extremity of a long cord, Fig. 129, be briskly moved up and down, wave-like motions pass rapidly from one end to the other. The particles which compose the cord do not advance; they only move from side to side; the undulatory *motion* alone flows on. If we toss a stone into still water, waves arise at the point of disturbance, and pursue each other in rapidly extending circles; there is no current; light objects are not drifted forward; the water particles only rise and fall while the wave progresses. By wave length is

FIG. 129.

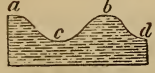


Undulation of a Cord.

317. What is the old hypothesis of light? What must a true theory of light explain? 318. How does sound move? In what way is it propagated? 319. What does the cord illustrate? What is it that goes forward? Describe the motion of water waves. How do the water atoms move? What is a wave length? 320. How

here meant the distance from the crest of one wave to that of the next, or from depression to depression, as from *a* to *b*, Fig. 130, or from *c* to *d*.

Fig. 130.




Wave Length.

**320. Sound Waves.**—So also a vibrating sonorous body, as a bell, throws the aerial particles into agitation, and the undulations sent through the air breaking upon the nerves of hearing, the effect is transmitted to the brain as sound. A harp string, for example, is vibrated, and as it advances, it crowds together or condenses the air particles before it; as it retreats, the air particles behind it separate more widely, and a rarefaction occurs. Advancing again, another condensation is produced; and again retreating, there is another rarefaction. A condensation and a rarefaction constitute a *sound wave*—its length being the distance from the centre of one condensation to the centre of the next, or from the centre of one rarefaction to that of the next. These pulses are propagated through the air at the rate of 1,100 feet per second.

**321.** It is marvellous how slight an impulse throws a vast amount of matter into tremulous motion. We may easily hear the song of a little bird 500 feet above us; but before that note could have travelled to our ears, it must have filled with wave pulsations a sphere of air 1,000 feet in diameter, or have thrown into agitation nearly 18 tons of atmospheric gases.*

**322.** The *pitch* of sound depends upon frequency of vibrations. The quicker a string vibrates, the more rapidly will the pulses follow each other; the shorter will be the wave, and the higher the sound. Hence, the violinist, to produce a higher note, shortens the string by pressing his finger upon it. Shrill notes are caused by rapid vibrations, while the low notes result from those which are slower. The lowest note of a 7-octave piano is made by 32 vibrations per second; the highest by 7,680, while each interme-

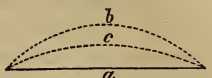
* Guns are fired in the Alps to start avalanches by the concussion of the air, and it is said that great masses of snow are often poised with such perfect equilibrium that the sound of the voice alone is sufficient to dislodge them. Speaking of the chamois hunters, ROGERS says:

'From rock to rock, with giant bound,
High on their iron poles they pass;
Mute, lest the air, convulsed with sound,
Rend from above a frozen mass.'

Is sound produced? How does a harp string affect the air? What is a sound wave? Its length? Velocity? 321. What is said of the power of a little bird to agitate the air? 322 Upon what does *pitch* depend? How are sharp notes caused?

diate note has its fixed number. *Intensity* or loudness of tone depends upon the intensity with which the air is struck by the vibrating body, or the amplitude of the excursions of the vibrating particles. A string that swings from *a* to *b*, Fig. 131, will produce a louder sound than if vibrating no farther than *c*, though the pitch will be in both cases the same.

Fig. 131.




Sweep of Vibration.

**323. Ether.**—Now the radiant forces are believed to be all propagated by undulatory motions; but motions in what? Sound has its medium—the air; and the sound rays cannot cross a vacuum, as there is nothing to convey them. But heat, light, and the chemical force dart through the most perfect vacuum we can produce, and traverse in all directions the interstellar spaces. There must be something throughout these spaces to transmit the motion. The wave theory of light assumes the existence of a universal *ether*—an infinitely rare and elastic medium which is diffused through nature, pervading even the most solid bodies. It connects atom with atom and star with star. Through this universal medium—the dynamic bond of nature—waves are sent with a velocity far exceeding those of sound.

**324.** It is objected to this idea of ether that it is a pure creation of fancy, like caloric and phlogiston (579). It is urged that as we know the forces only as manifested in matter, and as a perfect vacuum has never been produced, it is better to assume that some form of *actual matter* is universal, and that the wave motions take place in *that*. But it is after all very much a question of terms. Both views assume a universal medium capable of transmitting undulatory motions; one calls it *material*, and the other *ethereal*. Ether is not held to be *force*, but only the medium for representing those motions by which force is transmitted. One ether suffices for all the forces, and thus by introducing the idea of *unity* in their modes of action, we are prepared to comprehend their mutual relations. While the theory of ether may be objected to on some grounds, yet it is a vast advance on former

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What is said of the piano? What is intensity? How illustrated? 323. What is believed of all the radiant forces? Why is there probably a universal medium? Describe the ether. Its uses. 324. What objection is made to ether? What has to be assumed at any rate? What is ether held to be? What is gained by the conception? What has an eminent authority remarked, and why? 325. How is

ideas, and so combines and explains a multitude of facts which cannot be otherwise accounted for, that an eminent authority has remarked, 'If it is not true, it deserves to be!'

325. **Cause of Colors.**—According to this view, light is transmitted by ethereal undulations just as sound is by those of the atmosphere; with only this difference, that while the air particles move backward and forward in the same direction as the advancing wave (*normal vibrations*), the ethereal particles move across the course of the wave (*transverse vibrations*). Thus the spectrum is to the eye what the gamut is to the ear. As the pitch of sound depends upon the length of the air wave, so the color of light depends upon the length of the ethereal wave; and as loudness of sound depends upon the extent of the swing of air particles, so the brightness or intensity of color results from the extent of the excursions of the ethereal particles.

326. By several refined methods which cannot be detailed here, the lengths of the ethereal waves upon which colors depend have been rigorously established. The motions which produce red are slower, and the undulations longer than those which produce violet. It is found that 39,000 waves of red light would measure an inch, while 57,500 waves of violet light would fill the same space. The other colors are intermediate, their number of waves increasing gradually from red to violet. As light moves 192,000 miles per second, that length of ray streams into the eye each second. If this distance be reduced to inches, and the product be multiplied by 39,000, we shall have the number of waves which beat against the retina each second, when we look upon a red color. If the same product is multipled by 57,500, we get the number of pulses per second which strike the retina when looking upon a violet color. If a single second of time be divided into a million of equal parts, a wave of violet light trembles or pulsates in that incredibly short interval, 727,000,000 times! If these results seem incredible, we should remember that we are dealing with the resources of the INFINITE. In treating of atoms we saw the minuteness of the scale upon which nature divides her spaces, and here we have her corresponding infinitesimal scale of time and force.

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the motion of light explained? Difference between light and sound motions? To what is the spectrum compared? Upon what do color and brightness depend? 326. What are the lengths of the red and violet waves? What is the velocity of

**327.** It is necessary to distinguish between vibrations and undulations; the former take place among the atoms in all kinds of matter, the latter only in the transmitting medium. In the case of sound, the vibrations of a sonorous body produce undulations in the air, which, when falling upon other bodies, may set them also to vibrating. So the vibration of atoms in a flame, produces undulations in the ether; these are transmitted to the nerve of vision, and, breaking against it, throw its atoms into the vibrations which produce sight.

**328.** The nerves of hearing can be acted upon only by a certain range of air pulsations. There are air waves which fall upon the ear in regular recurrence, but exert no sensation; they are either too slow or too fast. It is probable that the hearing organs of different animals have still different ranges of sensibility, perceiving sounds which are too high or too low for the human ear. Just so with the ethereal undulations; the nerve of the eye is adapted to a certain range of pulsations, and waves too slow or too rapid do not awaken the sensation of light.

**329.** The colored spectrum, Fig. 127, embraces the range of ethereal undulations which produce luminous effects: below it are waves too slow to act upon the eye, while above it they are pitched too high. We shall soon refer to still more remarkable analogies between sound and light. But it is really no more extraordinary that myriads of ethereal waves beating incessantly upon the retina, should awaken the sensation of vision, than that a storm of air waves pouring upon the ear, perhaps from a hundred instruments at once, should give us the experience of music. Nature produces the most varied results by the simplest means; conveying to us harmony and beauty—the anthem and the landscape by the same method.

## § III. *Thermal Radiations.*

**330.** Heat is associated with light; it moves with the same remarkable velocity; is weakened by diffusion at the same rate, and is reflected, absorbed, transmitted, and refracted by various

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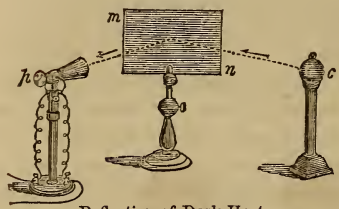
light? How many inches per second? How many red waves enter the eye each second? Of violet? 327. What is the distinction between vibrations and undulations? 328. What is said of the range of audible sensation? 329. Is the eye sensitive to all ethereal waves? What is said of the unity of nature's methods?

bodies in accordance with the same laws as light. When thus moving, it is called *radiant* heat.

**331. Luminous and Obscure Heat.**—Radiant heat is of two kinds: that which accompanies light is called *luminous* heat; that which is emitted from dark bodies, as a stove below redness, is termed *obscure* heat. That dark radiations of heat obey the same laws of motion as light, may be proved by placing a warm iron ball, *c*, Fig. 132, opposite the thermo-electric pile *p*, the conical reflector being turned away, so that no direct heat can reach it from the ball. A bright tin screen, *m n*, is then so placed that the angle made by the incident heat from the ball shall be the same as that reflected from the tin surface which strikes the pile. The moment the screen is placed in position, the needle of the galvanometer starts, showing that reflection has taken place.

Fig. 132.




Reflection of Dark Heat.

Fig. 133.

Thermal Spectrum.

**332. Thermal Spectrum.**—When a ray of light is decomposed by the prism, it is found that the heat is refracted like light, and is distributed through the colors, but the refrangibility is lower, and dark heat is therefore found below the red ray. The thermal spectrum was first traced by Sir John Herschel, and found to have the outline represented in Fig. 133, its lower part being curiously discontinuous.

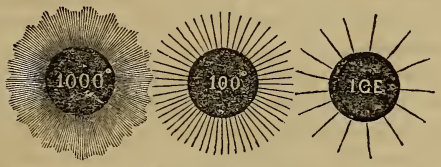
**333. How Radiation takes place.**—We can now explain thermal radiation in harmony with the later views of the nature of this force. As heat consists in the vibration of the particles of common matter, this motion is communicated to the ether in which they are immersed, and propagated through it exactly in the manner of light. The ethereal pulsations, striking against other substances, increase

330. What are the analogies of the motion of heat and light? What is radiant heat? 331. What is luminous heat? Obscure heat? What does Fig. 132 illustrate? 332. What is the thermal spectrum? 333. How is the radiation of heat

the vibration of their particles, and thus heat them. As a body cools, it loses atomic motion—the ether transmits this motion, and other bodies acquiring it are thereby warmed.

334. **Exchanges of Heat.**—All bodies, though at a hundred degrees below zero, contain some heat; that is, their atoms are all in vibration, though at varying rates. This motion must be communicated to the ether, so that all bodies radiate heat at all times, and are hence constantly exchanging it with each other. If a cannon ball at 1000° be placed beside another at 100°, it parts with its own motion rapidly to the other, as illustrated by the radiant

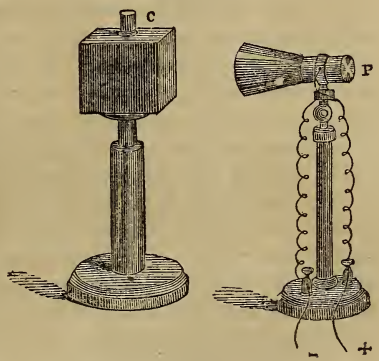
FIG. 134.




Exchanges of Heat.

lines, Fig. 134. But the ball at 100° also radiates its motion, though more slowly, thus returning a portion to the hotter ball; and if a ball of ice were added, the same thing would take place, only in a feebler degree. If a body receives motion faster than it communicates it, its temperature rises; if the reverse, it cools, and if the exchanges are equal, there is equilibrium, or a uniform temperature. Hence, other things being equal, the rate of radiation depends upon temperature.

FIG. 135.




Radiation from Leslie's Cube.

335. **Influence of the Surface.**—But thermal radiation is also influenced by surface. In Fig. 135, c represents a

explained? What is the part played by the ether? 334. Why must bodies constantly exchange heat? What does Fig. 134 illustrate? What is the cause of equilibrium? 335. How do surfaces influence radiation? What are the best

cubical vessel of pewter with one of its sides coated with a layer of gold, a second with silver, a third with copper, and a fourth with varnish. The vessel is then filled with hot water, and placed at a little distance from the thermo-electric pile P. When the hot gold surface is turned to the pile, scarcely a trace of effect is observed, and so with the copper and silver; but when the varnished surface is brought round, a stream of heat strikes the pile, and the needle is driven round against its stops. The condition of the surface also influences radiation—rough, uneven surfaces being more active than bright polished ones; hence, if the metal is covered with woollen or velvet, its radiant power is increased. Bright metallic vessels, therefore, retain the heat much longer than those which are tarnished.

336. **Absorption.**—Good radiators are good absorbers of heat; that is, the surfaces which can easily communicate motion *to* the ether are equally capable of accepting it *from* the ether. On the contrary, a bad radiator, as a bright metallic surface, is a bad absorber, and therefore a good reflector. Hence, the thinnest metallic film upon a surface powerfully protects it from the action of radiant heat.

337. As bodies differ widely in their atomic condition, it is not to be expected that they will all act alike upon the ether; some will communicate more motion than others. This explains the different radiating and absorbing action of bodies. Atoms vibrating singly cannot impress as much motion upon the ether as vibrating groups, or systems of atoms. The atoms of the elements—gold, silver, copper—vibrate singly, and disturb the ether but slightly; while those of varnish, flannel, or velvet oscillate in masses, and transmit an increased amount of motion.

338. **Influence of Color.**—According to Melloni, color exerts no influence upon the radiant power of surfaces; white, black, and red radiating alike, so that as regards the loss of heat from this source, the color of our clothes is of no importance. On the contrary, color powerfully influences the *absorption of luminous* heat. Dr. Franklin spread differently colored pieces of cloth upon the snow in the sunshine. The black sunk farthest, that is, melted most snow, and, of course, received most heat. The blue piece

radiators? The purest? 336. How are radiation and absorption related? 337. What are we to expect from the atomic peculiarities of bodies? What kinds of atoms affect the ether least? What most? 338. How does color affect radia-

sunk to a less depth, the brown still less, and the white hardly at all. Hence by scattering soot over snow its melting may be hastened. Darkening a soil in color, is, therefore, equivalent to moving it farther south, and, for the same reason, black clothes absorb most solar heat.

**339. Dew.**—When the radiation of bodies is not compensated, their motion is gradually spent upon the ether, and their temperature sinks. Such is the case with objects exposed to the sky on clear nights. If good radiators, they rapidly lose heat, and, cooling below the temperature of the air, at length begin to condense its moisture upon their surfaces: this is *dew*. The best radiators, as grass, leaves of trees, and porous soils, receive the most dew, while poor radiators, as smooth stones, and hard compact soils, remain almost dry. Clouds radiate back the heat received from the earth, so that cloudy nights are warm and dewless. If the temperature sinks lower than 32°, the moisture is frozen, and becomes frost.

**340. Transmission and Destruction of Waves.**—An opaque body destroys the luminous waves which fall upon it, while a transparent one permits them to glide through between the atoms without interference. But there are bodies which destroy some of the waves and allow others to pass. If a piece of red glass be placed between the prism and the spectrum, it stops the blue rays and transmits only the red, that is, it cuts down the more minute waves, and gives passage only to the larger. If blue glass be used, there is a reverse effect, the red waves being extinguished, and the blue alone transmitted. Both glasses are transparent, yet if placed together in the path of the rays, they are as opaque as a plate of iron; each destroying what the other transmits. If a solution of permanganate of potash be used in the same way, it destroys the central waves of the spectrum, leaving the colors of the extremities with a jet-black space between.

**341. Diathermancy.**—This is also the case with the heat rays; they are of different kinds, like the colors of light, and are arrested and transmitted differently by different substances. Bodies which transmit heat freely are called *diathermic;* those which arrest it, *athermic.* Rock salt (common salt in blocks) is the most perfect

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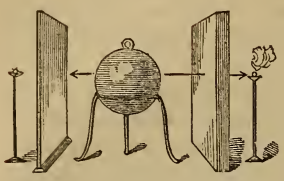
tion? Absorption? 339. How does dew depend upon radiation? 340. What is the effect of red glass upon the decomposed waves? Of blue? Of both? Of solution of permanganate of potash? 341. What are diathermic bodies? Athermic? What are the properties of rock salt? What has it been termed? What is

diathermic body, allowing all the heat rays—those from the sun and the hand to pass through with equal freedom. What glass is to light, a plate of rock salt is to heat, and it has hence been aptly termed 'the glass of heat.' This substance is therefore adapted to make prisms and lenses for the concentration and dispersion of dark heat. If a heated ball be placed between a plate of glass and one of rock salt, Fig. 136, and bits of phosphorus be laid upon stands beyond, though the salt be many times thicker than the glass, the dark heat passes freely through it, igniting the phosphorus, while it is quite arrested by the glass. In the same way a thin film of water will absorb the obscure heat, while liquid bisulphide of carbon will transmit it. The relations of different substances to the radiants are represented in the figures. The dotted arrows represent light; the broken arrows, luminous heat, and the whole, or dark arrows, dark heat. If the plate of salt be smoked, it becomes opaque to light, but the heat still passes, while plates of transparent alum are opaque to obscure heat, and almost impervious to luminous heat.

Fig. 136.

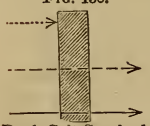


Glass intercepting, and Rock Salt transmitting Heat.

Fig. 137.

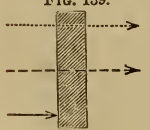
Rock Salt.

Fig. 138.



Rock Salt Smoked.

Fig. 139.



Glass.

Fig. 140.

Alum.

**342. Sifting the Rays.**—We have said that the sunbeam is a bundle of heterogenous radiations, and that the prism spreads them out into a spectrum, thermal at one end, chemical at the other, and luminous in the centre. The same thing holds true of all sources of heat, luminous and obscure—they emit rays of different qualities. When the mixed rays from any source are passed through a plate, a certain portion of them is stopped, and another portion transmitted. But if the rays which have passed are made to

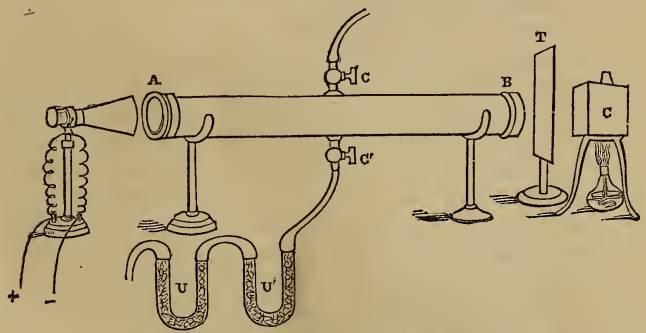
it fitted for? What is shown by Fig. 136? How is rock salt related to the three radiations? Smoked salt? Glass? Alum? 342. When mixed rays pass through a substance, what is the effect? How are they treated by a second similar plate?

fall upon a second similar plate, a much larger proportion will be transmitted than went through the first. The first plate *sifted* the ray, and the purified beam is better fitted to penetrate another similar plate. For example, a plate of alum stopped 91 per cent. of the heat rays, transmitting but 9; while a second alum plate transmitted 90 per cent. of the sifted rays, stopping but 10.

**343.** This principle explains the fact that glass readily transmits solar heat, while it stops the heat from a red-hot cannon ball in large quantities. The rays of the sun in coming through the atmosphere are strained of the rays which would be stopped by glass, so that the altered beam passes our windows without loss.

**344. Absorption of Heat by Gases.**—Some new and highly interesting results have been lately arrived at by Prof. TYNDALL on the relations of radiant heat to gases. The instrument he employed consisted of a hollow tin cylinder, A B, Fig. 141, four feet

FIG. 141.




TYNDALL'S Apparatus for Gaseous Absorption.

long and three inches in diameter. This is closed by caps containing plates of the purest rock salt, which are screwed air tight upon its ends. The upper stopcock, C, connects the cylinder with an air pump by which it may be exhausted, and through the lower stopcock, C′, air or any other gas may be admitted. The bent tube, U, contains fragments of pumice stone, moistened with caustic potash, to absorb carbonic acid from the entering air; and

How do the two alum plates behave toward heat rays? 343. Why does solar heat pass through glass, while that from a hot ball is stopped? 344. Of what parts does TYNDALL'S instrument for investigating the relations of heat to gases consist?

U′ contains pieces moistened with sulphuric acid, to absorb watery vapor. At one end of the cylinder is placed the thermo-electric pile, with wires leading to the galvanometer, and at the other a cube, C, filled with hot water; while a tin screen, T, cuts off and admits the rays.

345. **Pure Air Diathermic.**—If the cylinder be exhausted, and the screen withdrawn, heat enters, and traversing the vacuum, falls upon the pile without any loss; none of it is absorbed on the way. If now the cock C be turned, and purified air be allowed to enter and fill the cylinder, there is no motion of the needle; the air arrests none of the heat. 'Its atoms are apparently incompetent to shatter a single calorific wave: it is a practical vacuum as regards the rays of heat.' By a modification of the apparatus far more delicate, and after thousands of experiments, Prof. TYNDALL found that dry air did exert a slight influence, deflecting the needle about one degree. Pure oxygen, hydrogen, and nitrogen behave like air, being almost neutral.

346. **Influence of Compound Gases.**—If now compound gases are introduced into the cylinder, a remarkable effect appears. Olefiant gas, which is just as transparent as the air, arrests four fifths of the rays of heat. Pure, transparent ammonia is still more impenetrable, and arrests the heat as if the cylinder were filled with ink or pitch. The same effect is produced if only a small proportion of these gases is mingled with the air of the cylinder. To such an extent is this true that it has been affirmed that the ammonia escaping from a bottle of hartshorn by a single act of inhalation, will exert a more potent action on radiant heat than the whole body of oxygen and nitrogen in the apartment. Some bits of paper were moistened and placed in tubes, so that the entering air carried with it a faint trace of odor. The effect was marvellous: the aromatic vapor struck down the heat rays in crowds. The exhalation of bergamot arrested 44 times as much heat as the air; that of lemon, 65 times; and of aniseed, 372 times. The absorbent power of the following gases is represented by the accompanying numbers: air, 1; oxygen, 1; nitrogen, 1; hydrogen, 1; chlorine, 39; carbonic acid, 90; olefiant gas, 97; ammonia, 1.195.

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Explain their uses. 345. What is the effect when the cylinder is exhausted? When filled with pure air? What did TYNDALL ascertain with a more delicate instrument? 346. What is the effect of olefiant gas? Of ammonia? What is the effect of a trace of ammonia? Of odors? 347. How are these effects explained?

347. The same explanation applies here as in the former case (337). We saw that in solids, single atoms, or the atoms of elements, communicated their motion to the ether in a very imperfect manner, while compound groups produced more powerful effects. The same general fact now appears under totally different circumstances. The atoms are no longer embarrassed by cohesion; their movements are perfectly free, yet here again the elements oxygen, hydrogen, and nitrogen can only act upon the ether in the feeblest degree, while those of the compound gases which move in massive groups, are thrown into powerful vibration by the ethereal waves, and react upon them with corresponding energy. Prof. TYNDALL remarks that oxygen, hydrogen, and nitrogen swing in the ether with hardly any loss of moving force; they bear the same relation to the compound gases that a smooth cylinder turning in water does to a paddle wheel.

348. Invisible rays thus become the means of sounding the atomic constitution of bodies. While heat passes through common oxygen without being intercepted, ozone, which is but another form of oxygen, arrests a large proportion of it like compound gases; we therefore infer that its atoms are arranged in groups. Lampblack is an excellent radiator, and though an element, yet it is an allotropic condition of carbon, in which the atoms are probably grouped into complex molecules.

349. **Absorption of Heat by Aqueous Vapor.**—These views are not only interesting in themselves, but of the utmost importance in the economy of nature. Aqueous vapor is highly opaque to the dark radiations. Where the atmospheric gases arrest one ray of obscure heat, the small proportion of watery vapor contained in the air strikes down sixty or seventy rays. Luminous solar heat penetrates the air, and falling upon the earth, is changed into obscure heat, which cannot be radiated back into space. The watery vapor is thus the 'barb' of the atmosphere which prevents the escape of the heat, and thus maintains the temperature of the earth. It follows that if aqueous vapor were withdrawn from the air, the terrestrial heat would so quickly radiate away, that the earth would soon become uninhabitable; the invisible watery element of the air is, therefore, the blanket which keeps

To what are the different atoms in the ether compared? 348. What work do the invisible rays perform? 349. What is the relation of aqueous vapor to obscure heat? What is the effect of the aqueous vapor of the air? What would be the

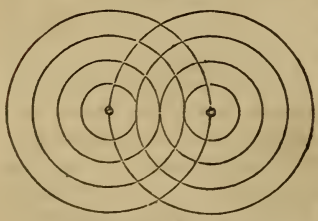
the world warm. In all those localities where the atmosphere is *dry*, the nightly loss of radiant heat is great, so that even in the burning desert of Sahara there is nocturnal freezing.

**350.** The sun's rays fall with intense power upon the snowy summits of high mountains, but their ice never melts. Travellers testify that they have never suffered more from solar heat than when wading waist deep in the snows of Alpine mountains. But there is so little aqueous vapor in the higher atmospheric regions, that the heat escapes as fast as it is received, and thus high mountains are powerful condensers of the vapor which is brought by the air currents from below (574). 'Water *in all its forms* is so active a radiator, that it must play a most important part in this mountainous condensation. As vapor it pours its heat into space, and promotes condensation; as liquid it pours its heat into space, and promotes congelation; as snow it pours its heat into space, and thus converts the surfaces upon which it falls, into more powerful condensers than they would otherwise be. Of the numerous wonderful properties of water, not the least important is this extraordinary power of discharging the motion of heat upon the interstellar ether!'—(TYNDALL.)

## § IV. *Interference of the Radiants.*

**351. Interference of Waves.**—When two sets of waves upon water are made to flow together, two effects may take place. If the waves coincide, that is, if ridge corresponds to ridge and furrow to furrow, their height will be *increased;* but if the ridge of one corresponds with the trough of another, they will *neutralize* each other and the water become still. This is called *interference.* If one of the systems be retarded a whole wave length, or any number of *whole* wave lengths, there will still be no interference; but if one be retard-

FIG. 142.



Interference of Water Waves.

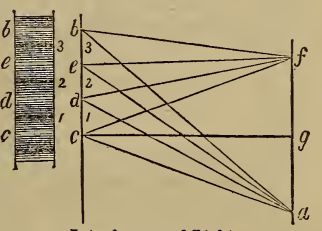
effect of removing the aqueous vapor from the air? 350. What is said of the heat upon high mountains? Why does not the snow melt? What is the effect of the radiation of water in all its forms? 351. What is interference of water waves?

ed half a wave length, one and a half, or two and a half, the hills will neutralize the hollows, and interference produce rest. These effects may be shown by dropping two stones into still water near each other at the same moment. Two sets of concentric waves are formed, Fig. 142, and where their circles intersect each other and their crests coincide, the motion is heightened; but where crest coincides with depression, their motions are mutually destroyed.

**352.** Again, two stretched strings, or two tuning forks, may be so arranged, that, when simultaneously struck, they do not give forth a continuous sound; but there is produced a series of sounds, alternating with a series of silences. For a moment the sound increases, then dies away and ceases, then again swells forth and declines, and so continues until the strings or the forks cease vibrating. During the pauses of silence, there is still rapid vibration, so it is certain that the sounds are extinguished by interference of their waves.

**353. Interference of Light.**—If a beam of *colored* light be admitted into a dark room by two pinholes made near each other in a thin sheet of metal, and be made to fall upon a screen at a short distance, the rays intersect each other, and a series of dark bands alternating with bright stripes will be formed upon the screen by interference of the ray from the two orifices. In Fig. 143, *a f* represent the two pinholes, and *c d e b* a portion of the screen, *c g* being a line joining the two surfaces at right angles, and midway between the pinholes. The rays, *a c*, *f c*, pass through equal paths; their waves coincide at *c*, and, heightening each other's effect, a bright band is produced at *c*; *a d*, *f d* will differ by the length of one wave, *a e*, *f e* by the length of two waves, and *a b*, *f b* by the length of three waves; hence, there will be also bright bands at *d*, *e*, and *b*. But the rays from the two orifices, meeting at 1, 2, 3, differ in length successively by half a wave, a wave and a half, and

Fig. 143.




Interference of Light.

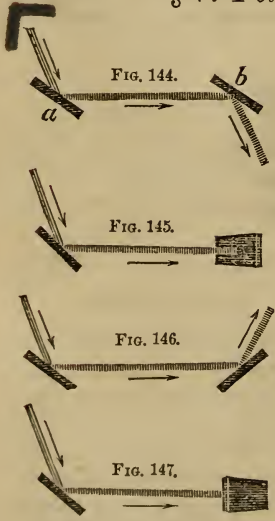
How may these effects be shown? 352. How is interference of sounds manifested? 353. How may interference of light be produced? Describe the experiment.

two waves and a half, and by thus interfering, extinguish each other and produce darkness. As the rays which meet at *c* are equal, it is obvious that all the other rays coming from *a* are lengthened, and all others coming from *f* are shortened. As this variation of length is gradual, there will be a gradual passage from the brightest light to complete darkness. This effect is exhibited by the shaded portion of the diagram. If the light from one aperture is intercepted, all the dark bands disappear.

**354.** The multiplicity of these remarkable phenomena is proof of the extent to which wave motion is employed in nature. Thus we have seen that motion added to motion produces rest; that sound added to sound produces silence; that light added to light produces darkness; and it has also been proved that heat added to heat produces cold, and chemical energy added to chemical energy produces inaction: in other words, there may be interference of the thermal and chemical radiations just as of light and sound.

Skip from here to Conservation of Force

## § V. *Polarization of Light.*



Light Polarized by Reflection.

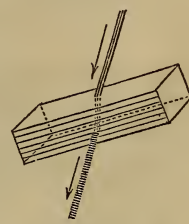
**355.** When light is reflected at certain angles from the surface of glass, water, marble, polished wood, &c., a portion of it undergoes a remarkable change. Although taking place all around us constantly, we do not perceive it, but it may be detected in various ways. Two plates of glass are blackened on one side so as to have but a single reflecting surface, and then placed as shown in Fig. 144, *a*, *b*, with their edges toward the eye. A ray of common light falling upon *a* in the direction of the arrow is reflected, and, upon being thrown upon *b*, is again reflected. The ray is changed at *a*, as the altered structure of the line shows, but the effect is not apparent. If now

354. What is the extent of this principle? 355. What happens when light is reflected at certain angles? How is this change detected? What is the effect of

*b*, or the second plate, is turned a quarter round, its angle with the ray being preserved, reflection ceases, and the beam is extinguished, Fig. 145. Turning it another quarter round, Fig. 146, the ray is again reflected; and still another quarter revolution, Fig. 147, brings it on the opposite side to Fig. 145, and again extinguishes it. The beam may be reflected from surface to surface any number of times *in the same plane;* but it has lost the ability of being reflected in planes *at right angles* to that plane, while common light may be reflected in all directions. It thus appears that the ray has acquired *different properties on different sides.* From its analogy to magnetic polarity, this change is called *polarization*, and the ray thus affected is said to be *polarized.* The angle at which the ray falls upon the polarizing surface is called the *polarizing angle*, and differs in different substances: for glass, it is 56° 45′, while for water it is 53° 11′.

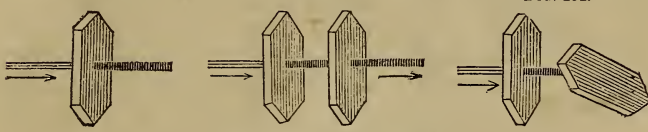
**356. Polarizing by Transmission.**—Light transmitted obliquely through a bundle of thin glass plates, Fig. 148, is polarized, and the same effect is also produced by its passage through certain crystals. A stone, called the *tourmaline*, is much used for polarizing purposes. A thin polished plate of it polarizes the light which passes through it, as in Fig. 149. If a second plate is placed parallel to the first, Fig. 150, the light passes through both; but if the second plate is turned a quarter round, Fig. 151, the light is stopped. 'The rays of the meridian sun cannot pass through a pair of crossed tourmalines.' The plate

Fig. 148.



Polarization by Thin Plates.

Fig 149. Fig. 150. Fig. 151.



Polarization by Tourmalines.

polarizing the light is called a *polarizer*, that which tests or detects it after it is changed, is termed the *analyzer.*

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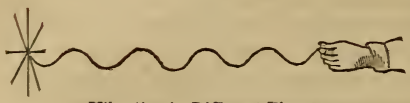
turning the plate *b*, fig. 144? How may the changed beam be reflected? What has the ray acquired? What is it called? What is the polarizing angle? 356. In what other ways may light be polarized? How do a pair of tourmalines affect the ray?

**357.** The wave theory affords a beautiful explanation of these phenomena. To recur to the illustration of the cord, it is obvious we can vibrate it up and down, horizontally, or in any direction transverse to its length, Fig. 152. In common light the undulations take place in *all* these directions at once. It has been suggested that common light may be represented by a *round* rod; polarized light by a flat one. Supposing the round rod to image to us the common ray, the

Fig. 152.



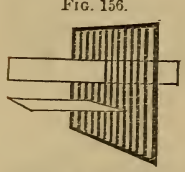
Vibration in Different Planes.

Fig. 153. Fig. 154. Fig. 155.

Illustrations of Planes of Vibration.

radii, Fig. 153, will exhibit the system of transverse vibrations taking place in all planes. But the effect is just the same if we regard the vibrations as taking place in *two planes* only, at right angles to each other, as in Fig. 154. Now when common light is reflected in certain positions, which we have just noticed (355), one of its planes of vibration is destroyed, and the beam is polarized, *its vibrations taking place all in one plane*, Fig. 155. We can now easily understand the action of the tourmaline upon light. A plate of this crystal suppresses one of the planes of vibration, and, therefore, transmits a polarized ray. This will pass through a second plate if it is held in such a manner that its structure coincides with the motion; but if it is turned so as to cross the waves, the ray is obstructed. A card which readily slips through a grate when its plane coincides with the bars, will be stopped if it is turned a quarter round, Fig. 156.

Fig. 156.



Motion in a Single Plane.

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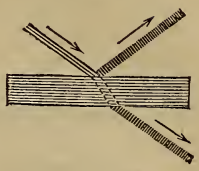
What is the polarizer? The analyzer? 357. How do the undulations take place in common light? What does figure 153 show? 154? What is the effect of the reflection, Fig. 155? How does the tourmaline polarize light? How does the figure

**358.** When a ray falls upon a transparent surface at a certain angle, its planes of vibration are *resolved into two*, one of which is reflected, and the other transmitted, Fig. 157; both are polarized, but one ray vibrates in one direction, and the other in another.

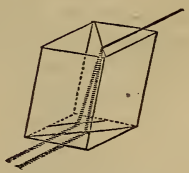
Fig. 157.



Polarized Rays.

**359. Double Refraction.**—Some substances possess the singular property of splitting the ray which passes through them, producing an effect which is known as *double refraction*, Fig. 158. Iceland spar (a carbonate of lime) and many crystals possess this power; printed words or a candle flame seen through them appearing double Fig. 159. The effect is due to the molecular structure of the body. A cube of annealed glass, which usually gives only single refraction, if unequally heated or subjected to pressure, divides the ray and manifests double refraction. The wave theory affirms that in double refraction the ray of common light has its two systems of undulations *separated*, and that the resulting rays must, therefore, be polarized, and at right angles to each other. Such is the fact; and if the beams be intercepted by a plate of tourmaline, one is stopped, and the other transmitted.

Fig. 158.



Double Refraction.

Fig. 159.

Effect of Double Refraction.

**360. Circular Polarization.**—Light affected in the manner described is said to be *plane polarized*. If the end of the cord, Fig. 152, be moved in a circle, circular waves will be formed, and so we have also *circular polarization*. The wave motion is similar to that which a strip of card would have if forced along two opposite grooves of a rifle barrel. Some substances rotate the ray in one direction, and some in another, while some rotate it more than others, but in each case the degree of rotation depends upon

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of the card and grate illustrate this? 358. How may the ray be separated? 359. What is double refraction? How is it manifested? Upon what does it depend? How does the wave theory explain it? 360. How is circular polarization illustrated? How do bodies differ in relation to this property? How is the prop-

the thickness of the medium. Solutions of sugar and most essential oils turn the plane of polarization, and this property thus becomes a test of the nature of chemical substances, and of the strength of various solutions. *Colored polarization* is a branch of the subject having extreme interest, but it is too complex to be considered here.

**361. Uses of Polarized Light.**—Not only is polarized light serviceable in the way just mentioned, but it has other applications. The use of the tourmaline *greatly diminishes the glare of reflected* light, so that objects at the bottom of water, as rocks, shoals, or fish, may be more clearly seen; and in the same way the pictures in a gallery may be better viewed.. It also affords a method of determining whether the light from celestial bodies is direct or reflected. In a scientific point of view polarized light has great interest as a means of revealing the inner constitution of various substances which is not detected by common light.

## § VI. *Spectrum Analysis.*

**362. Fraunhofer's Lines.**—When the spectrum formed from a narrow line of solar light is viewed by a telescope, it is seen to be crossed by numerous dark lines of various breadths. They were discovered in 1802, by Dr. Wollaston, but excited little attention until they were rediscovered by Fraunhofer in 1815. He counted 590 from the red to the violet, and made a map of them, designating the most important by the letters of the alphabet (315). He further found that the lines did not vary in sunlight, examined at different times; that the reflected light from the moon or from Venus gives the same distribution of them as the sun, while the spectra of the fixed stars differ from those of the sun and from each other. From these considerations Fraunhofer drew the conclusion that the cause of the lines in the spectrum *exists in the sun.*

**363. The Spectroscope** is an instrument for observing the lines of the spectrum. Fig. 160 represents it in its simplest form. Rays of light from the sun or lamp *a*, enter a narrow vertical slit in the tube *b*, and passing through the prism *c*, are refracted and

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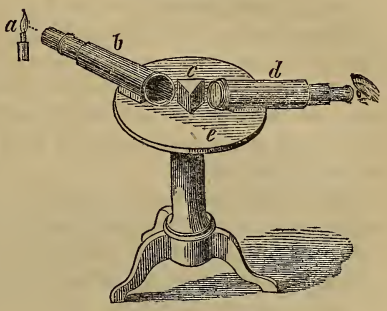
erty used? 361. What is the advantage of looking at objects through the tourmaline? 362. What are Fraunhofer's lines? What did Fraunhofer discover and

produce a spectrum. This is seen by looking into the spyglass *d*. The more perfect instruments have a third tube situated at *e*. which contains a scale for accurately measuring the spaces between the lines. To obtain a high dispersive power, hollow glass prisms filled with bisulphide of carbon are used, and several may be employed at once. When in use the whole is covered, to exclude the interfering light.*

Fig. 160.




The Spectroscope.

**364. Spectra of the Elements.**—It is commonly known that different substances tinge the flame of burning bodies of various colors, as seen, for example, in the colored flames of fireworks; but it has only lately been found that each element has, as it were, its 'mark,' or autograph of light. Each one, when burned under suitable circumstances, emits a light, which, when passed through the prism, produces a spectrum so peculiar that it may serve to identify the element from which it proceeds. The investigation of the spectra of the elements was lately undertaken by Kirchhoff and Bunsen, of Germany, and the interesting results open to us a new method of chemical analysis.

**365. How the Spectra are Produced.**—To emit their peculiar light, bodies must be *vaporized*. An ordinary lamp or gas flame may produce the result, but it is most brilliant in the electric light. If a platinum wire be heated to whiteness, and its light passed through the prism, it gives a *continuous* spectrum; but if it be con-

* The Spectroscope of Fraunhofer was first used in this country by Dr. John W. Draper, of the University of New York, more than twenty-five years ago. He modified it in 1842 in such a manner as to cast the fixed lines upon the sensitive surface of daguerreotype plates, and published a map of the results, showing four great groups of these lines beyond the limit of the violet ray, and probably doubling the number of lines up to that time known. About the same time Prof. Draper published several papers on spectrum analysis, anticipating various things which have been lately brought forward as new (399).

conclude? 363. What is the Spectroscope? Describe it. 364 How do different substances affect flames? What has been lately found? 365. In what condition do the elements require to be? Examples. What are the sodium lines? Do its

verted into incandescent vapor by the electric current, its spectrum becomes broken, and there is a series of brilliant lines separated by varying intervals of darkness. If zinc be vaporized, it gives beautiful bands of red and blue; if copper, they are of a brilliant green, while brass, which consists of both metals, gives both sets of lines at once. The metal sodium gives two very fine yellow lines situated close to each other, and so also does common salt and the other compounds of sodium. So amazingly delicate is this test that BUNSEN claims to have detected the $\frac{1}{50,000,000}$ of a grain of sodium.

**366. New Elements.**—As BUNSEN was examining the spectra of the alkalies, he observed some bright lines which did not belong to them, and which led him to suspect the presence of a new metal associated with these bodies. Further investigation proved the truth of his conjecture. On evaporating 40 tons of a certain mineral water, he obtained 105 grains of the chloride of a metal which gives two splendid violet lines in the spectrum, and which he called *Cæsium*, from *cæsius*, bluish gray. He obtained also 135 grains of the chloride of another metal, which gave two bright red lines, and which he named *Rubidium*, from *rubidus*, dark red. Mr. CROOKES has since discovered a new metal resembling lead, which is distinguished by a spectral band of bright green, and has hence been called *Thallium*.

**367. Coincidence of Bright and Dark Lines.**—In order to map the positions of the bright lines of various metals, KIRCHHOFF employed the dark lines of the solar spectrum as his guide. Upon placing one spectrum over the other, he was astonished to find that *whole systems of lines* in the two spectra were coincident; the bright lines of potassium, sodium, chromium, magnesium, iron, and nickel, exactly corresponding with the same number of dark solar lines. The spectrum of vaporized iron gave about 60 bright lines, which precisely coincide in grouping, breadth, and separation with the same number of dark lines in the spectrum of the sun. This could be no accidental result. KIRCHHOFF calculated that the chances are more than 1,000,000,000,000,000,000 to 1 that they are both due to the same cause, and that, therefore,

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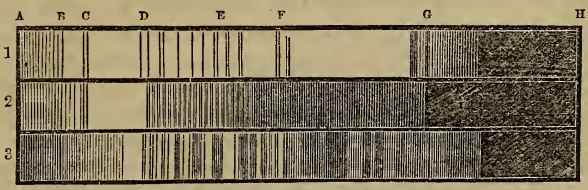
compounds give it? What does BUNSEN claim? 366. What led BUNSEN to suspect the existence of new metals? How did he proceed? What did he discover? 367. What discovery did KIRCHHOFF make? What did he find concerning the iron lines? What probability did KIRCHHOFF work out? 368. When light is

there must be incandescent iron vapor in the atmosphere of the sun.

**368. Dark Lines Produced by Absorption.**—When light is transmitted through certain vapors, and then passed through the prism, the spectra exhibit dark lines which vary in the different cases. Fig. 161, No. 1, shows the dark lines of the pure solar

FIG. 161.




Absorption of Light by Gases.

spectrum; No. 2, the influence of vapor of bromine upon the ray, and No. 3, that of the red fumes of nitrous acid. The wave theory explains these results. We have seen that gases and vapors destroy some of the rays of heat, and let others pass. The same thing occurs here; the vibrating atoms of the vapors strike down certain classes of the waves—they are absorbed, and hence the dark lines in the spectrum are *lines of absorption.*

**369. What Rays are Absorbed?**—This question carries us one step further in this interesting inquiry. We have learned in the case of heat that the good radiator is the good absorber; that is, that the same vibrations which emit a train of waves will also arrest them. The same thing is true of colors. 'The atoms which vibrate red light will stop red light; those which oscillate green, will stop green, and so of the rest.'

**370.** This remarkable fact is proved by throwing the ray of an electric lamp through a flame containing metallic vapor. The vapor will arrest the same kind of rays that it gives out, and its spectrum will be reversed, dark lines replacing the bright ones. For example, if an electric light is made to shine through the sodium flame, the two yellow lines of its spectrum are changed to dark lines. The rays that the sodium emits are also arrested.

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transmitted through vapors, what is the effect? How is this explained? 369. What principle prevails here which we have learned before? 370. How is this proved? If an electric light is passed through the sodium flame, what results? Are the dark lines

The dark lines thus produced, are, however, only *relatively* dark; the sodium continues to emit its bright lines, but the light intercepted is so much more brilliant than that emitted, that the lines appear as dark spaces in comparison with the rest of the spectrum. The dark lines are thus *lines of absorption.*

**371. Cause of the Dark Solar Lines.**—These views afford an explanation of the cause of the dark solar lines. Astronomy teaches that the sun consists of two parts; a central orb, or nucleus, of intense brightness, surrounded by a luminous atmosphere (photosphere), so that there are two sources of solar light. If the light from the central orb could be intercepted, we should receive only rays from the photosphere, and its spectrum would give us all the dark lines of FRAUNHOFER as bright lines, owing to the chemical substances which exist in it as vapor. But as the rays of the far brighter nucleus pass through the photosphere, it stops all those which it can itself emit, and thus gives us the dark lines of the solar spectrum as *lines of absorption.*

## § VII. *Chemistry of Light.*

FIG. 162.

Chemical Spectrum.

**372.** It was known to the alchemists that light exerts a chemical effect upon various bodies, as, for example, blackening the salts of silver. SCHEELE, a German chemist of the last century, proved that this effect is most intense in the violet region of the spectrum; and RITTER, of Geneva, in 1801, discovered the separate existence of dark rays more refrangible than the violet which produce chemical changes.

**373. The Chemical Spectrum.**—When a sheet of white paper is washed over with a solution of nitrate of silver, and the prismatic spectrum is made to fall upon it, a change occurs; the paper blackens. The outline of the darkened space is represented in Fig. 162. This third spectrum also exhibits a break or interruption like that of heat. The dark band is the point of no chemical action, and occurs in the yellow space. The radiations which produce these effects have been

absolutely dark? 371. What does astronomy teach concerning the sun? If the solar nucleus were abolished, what would be the result? How are the dark solar lines produced? 372. What facts concerning the effects of light were known to the alchemists? To SCHEELE? To RITTER? 373. How is the chemical spectrum formed? What is

termed the *actinic* rays, or *actinism*, a word which signifies literally *ray power*. They are, however, more commonly known as the *chemical* rays.

**374.** Thus the sunbeam is a line of forces through which the sun has a threefold control over terrestrial matter. It transmits an expansive energy which controls the magnitude and forms of bodies; a luminous influence which impresses the nerve of the animal eye, and a chemical force which governs affinity. Fig. 163 represents the position and intensities of the three forces in the prismatic spectrum. The course of the curve *a* defines the intensity and extent of the heat; *b*, of the light; and *c*, of the chemical force. The agency of light in the production of organic matter will be considered in Physiological Chemistry.

FIG. 163.

The three Spectra.

**375. Analogies of the Chemical Force with Light.**—That the chemical element of the ray is of the same nature as light, is proved by the completeness of its analogies with it. It moves in straight lines with the same velocity, and is diffused, reflected, refracted, double-refracted, and polarized like light. It also undergoes interference, and gives the lines of absorption; and as there are different kinds of light, so there are also different kinds or qualities of chemical force which take effect upon different classes of compounds and correspond to colors. We are thus brought to consider chemical action as a motion of atoms, and the chemical changes of the spectrum as produced by ethereal waves.

**376. How Light Produces Chemical Change.**—As the increase of vibration throws atoms beyond the sphere of cohesion, so it also throws them beyond the sphere of affinity, producing decomposition. In cohesion, the atoms are alike, and vibrate alike; in affinity, they are totally unlike, and vibrate at different rates. Elements, having the highest and lowest atomic numbers, as hydrogen and the noble metals, do not combine at all; their motions being so different that they cannot keep together. Others move at such rates that they unite only feebly, and the slightest increase of atomic motion separates them. A stream of waves, falling upon

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said of it? 374. What are the effects of the sunbeam? How are the three spectra situated? 375. In what respects is the chemical element of the ray analogous to light? 376. Upon what does affinity depend? What substances will not combine? How

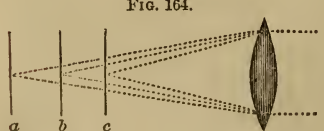
a group of unequally vibrating atoms, acts upon them unequally, and thus tends to increase the diversity of their motion. When the successive wave strokes are so timed to the motion of an atom as to increase its oscillations, the effect accumulates, the atom is detached and thrown within reach of new affinities. In this manner one compound is destroyed and another formed.

**377. Measurement of the Force.**—If hydrogen and chlorine gases are mingled together in the dark, their rates of vibration are so different that they do not unite. If brought into diffused daylight, they gradually combine; if into the sunshine, they combine explosively. This change is effected by the chemical rays which are absorbed; that is, the ethereal motions are taken up by the gaseous atoms which are thus brought into combining relations. The amount of condensation which occurs has been employed as a measure of the force in action (616).

**378. Photography.**—This beautiful art is a result of the chemical action of light. A metallic, glass, or paper surface is coated with some chemical substance which is changed by light, and, therefore, said to be *sensitive*. The prepared tablet is then placed in a camera obscura, a darkened chamber, with lenses on one side, by which the images of external objects are formed within. These are made to fall upon the sensitive surface, when a change takes place, its intensity corresponding to the intensity of the light. The brightest points are most changed, the darkest least, and those between intermediately, so that the lights and shadows pass into each other gradually. The processes for making pictures will be referred to after treating of the chemical substances used (870).

**379. The Picture Formed by a Dark Force.**—Photography or *light-drawing* is an erroneous term, as it is not the light which acts, but the dark radiations with which it is associated. Hence, as the chemical rays are more refrangible than the luminous, and are gathered to a point sooner, Fig. 164, the accurate operator makes allowance, and advances the prepared plate slightly forward from the luminous

FIG. 164.




*a*, Heat; *b*, Light; *c*, Chemical Force.

does the radiation produce decomposition? 377. How is the chemical force measured? 378. How are photographic impressions produced? How are the lights and shadows related? 379. Why is photography an erroneous term? How may a

to the chemical focus. By a proper arrangement, the chemical rays of the spectrum which are beyond the region of light, may be thrown into a darkened apartment against an object, and, being reflected upon a sensitive surface, will produce a picture in total darkness.

380. By reference to the curves, Fig. 163, it will be seen that light and the chemical force are antagonistic—where the former is strongest, the latter is weakest. As we approach the equator, therefore, the light becomes so brilliant as to interfere with the process, and make it difficult to take pictures.

**381. Instantaneous Impressions.**—A train of cars at high speed, if seen at night by a lightning flash, seems standing at rest: so a wheel revolving many hundred times a second in a dark room, if illuminated by an electric spark, appears to stand still—so incredibly brief is the duration of the light. Mr. Fox Talbot placed upon a wheel a printed bill so as to produce its image in a camera. He then darkened the room, placed a highly sensitive plate in the camera, set the wheel to revolving at the rate of 200 revolutions per second, and illuminated the apparatus by an electric spark. *A definite and legible impression of the bill was obtained.* While the light acted, the wheel could not have moved through the $\frac{1}{100}$ of a revolution, that is, the picture must have been taken in less than the $\frac{1}{20,000}$ of a second—one of the most astonishing results in the whole range of science.

**382. Chemistry of the Stars.**—According to the faith of the old alchemists, the earthly elements were ruled by the magical influence of the stars. It was a prophetic dream, and has been fulfilled in the consummate researches of modern science, which has given us a true *celestial chemistry*. The spectrum of the stars has its bands of absorption, and Mr. Rutherford, of New York, has discovered a coincidence between several of the dark lines of Arcturus and those of the sun—these lines being possible indications of the chemical conditions of their sources. The light of the stars also contains a positive chemical energy; they are photographed by the astronomer. He prepares his chemical map, and they telegraph across the universe, registering upon it their exact places. Though situated so profoundly in the depths of space

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picture be produced in darkness? 380. How are the chemical and luminous forces related? 381. Under what circumstances do moving bodies appear at rest? Describe Talbot's experiment? 382. What dream of the alchemists has science realized? What is the relation of the stars to earthly matter? What is their

that it may require thousands of years for their impulses to reach us, the stars, nevertheless, *exert a control over the conditions of earthly matter*, producing decomposition and regrouping chemical atoms. In fact light itself is a physiological force effecting nerve changes—a kind of vital photography in which the pictures are sensations, and translate the outer world into the sphere of consciousness. Thus the radiations of the heavenly bodies are the mysterious links which bind the vast universe to our world of matter, life, and mind.

383. **Phosphorescence** is a property possessed by various bodies of emitting a faint light at ordinary or low temperatures, and is so named from phosphorus, which exhibits it in a remarkable degree. Phosphorescence is manifested by certain insects, as the firefly and glowworm, by several species of plants, by various animal and vegetable substances in a state of decay, and by exposure of many substances to sources of light. If a sheet of paper or the hand be placed in sunshine for a short time, and then withdrawn into darkness, they will continue to glow for a few seconds, while other bodies, as the diamond and chlorophane, after exposure, remain for a long time luminous. The cause of these phenomena is not fully understood. It is maintained by some that there is a fourth class of rays in the sunbeam which have the power of exciting phosphorescence, and are hence called *phosphorogenic rays*. The diamond will not glow if protected from the sun by the thinnest glass; therefore, glass is assumed to be opaque to these rays; on the other hand, smoked quartz, which arrests the light, permits this effect to pass.

384. **Persistence of Impressions.**—Slight and evanescent as these effects may seem, they nevertheless cling to matter with surprising persistence. If we cover a board with powdered sulphide of calcium (made adherent by a previous coating of gum arabic), lay a key upon it, and expose it for a few minutes to sunlight; on bringing it into a dark room, and removing the key, a dark, well-defined image of it is seen on a white ground. The surrounding phosphorescent glow gradually diminishes, and the image disappears. Now, place a pencil upon the surface, and expose it again, and when the image vanishes, repeat the exposure a third

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physiological significance? 383. What is phosphorescence? How may it be manifested? What is said of its cause? 384. Are these effects persistent? By what

time with a ring. When all traces of the last image are gone, heat the board, and the images will reappear in reverse order—first, the ring, then the pencil, then the key; and they have been thus evoked weeks and months after they were formed.

**385. Universal Impressibility of Matter.**—It was at first supposed that light affected only a few peculiar substances, but the progress of chemistry has shown that the sunbeam can hardly fall upon a surface of any kind without producing a molecular change and leaving a lasting impression.

**386.** If an engraving which has been for some time in the dark is one half exposed to the sunlight, the other being kept perfectly covered, and then removed to a dark room and placed in close contact with a sheet of prepared photographic paper, the portion which was exposed to light is reproduced on the sensitive paper, while the protected part produces no effect. Again, an engraving, charged with sunshine and placed in the dark a quarter of an inch distant from a surface of sensitive paper, was reproduced without contact and by radiation of dark force.

**387. Moser's Images.**—It would, moreover, seem that one object can hardly touch or approach another without impressing a change upon it, which is more or less lasting. If we lay a wafer or small coin upon a piece of clean cold glass, or polished metal, and breathe upon the surface, upon tossing off the object, after the moisture has evaporated, not a trace of it remains. But if we breathe upon it again, a spectral image of the coin or wafer comes forth, which, as it fades away, may be again and again recalled by a breath, even months afterward. These images were discovered by M. Moser and Dr. Draper about the same time. Objects also impress each other without contact. Engineers have noticed that the near parts of machinery visibly impressed each other. By exposure over night, a very distinct image of the grain of wood has been obtained, when placed more than half an inch from the receiving surface.

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remarkable experiment is this shown? 385. What is said of the extent of these effects? 386. What experiments may be made with engravings? 387. Describe the experiment with the wafer. Who are its discoverers?

# CHAPTER VI.

## MUTUAL RELATIONS OF THE FORCES.

### § I. *Connection of Polarities.*

**388. Ideas of Force Progressive.**—With the progress of science ideas of force are refined. It was so in Astronomy. The earliest notion of the cause of celestial motions was that of *solid crystalline spheres* by which the heavenly bodies were supported and carried round in their courses. This idea was replaced by that of the more flexible mechanism of *epicycles*. To this succeeded DESCARTES's more refined hypothesis of *vortices*. He represented the planets and satellites as owing their motions to oceans of fluid diffused through the celestial spaces, which constantly whirled around in vortices, and bore along the heavenly bodies. NEWTON first cleared away these material devices, and substituted the idea of an immaterial force acting according to mathematically demonstrated laws.

**389.** So also with heat, light, electricity, and affinity; they have passed through their *material* stage, and are now to be regarded as kindred and convertible modes of motion. The present chapter will recapitulate some points already noticed, and still further illustrate the later and larger views of the relations of forces.

**390. Rise of the Idea of Polarity.**—NEWTON fixed the attention of the world upon the play of *central attractions* through the universe. This idea so completely occupied the thought of the last century that men fancied the entire mechanism of nature—molecules as well as masses—was moved by central attractions. But about the beginning of the present century it began to be perceived that another and widely different mode of force plays an important part in her scheme. This is the principle of *polarity*. We have seen it working in various forms, but in them all we discover the common characteristics of *opposite powers or prop-*

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388. What has been the progress of ideas of force in astronomy? 389. Has this principle been carried farther? 390. What was the influence of NEWTON in regard to forces? What principle has been lately brought forward? What

*erties in opposite directions.* A very intimate and interesting series of relationships may be traced among these polarities.

**391. Magnetic and Electric Polarities.**—In the case of magnetic and electric forces, it was suspected, long before OERSTED made the discovery, that they were in some way intimately related. This connection, however, turned out to be more constant and extensive than had been imagined. A magnetic needle, when placed near a galvanic wire, is jerked out of its position and turned across the current. A galvanic wire is made to revolve round a magnet, and a magnet round a galvanic wire. Artificial magnets are made of coils of galvanic wire; and, finally, the galvanic spark itself is obtained from the magnet. We cannot escape the conviction that whatever be the nature of these polarities, they are due to the same cause.

**392. Electric and Chemical Polarities.**—In chemical processes, opposites (acids and bases for example) are attracted together and neutralize each other. It is true we do not here have 'unlike poles attracting, and like poles repelling,' as in magnetism and electricity, but these are only special modes in which the principle of polarity is manifested, and are not essential to it. The conception of opposite properties and mutual neutralization involves the idea, and makes the chemical a true polar force. FARADAY teaches that chemical combination and decomposition must always be regarded as taking place in virtue of equal and opposite forces, by which the particles are united or separated; and he has used this very case to teach us that, in the general idea of polarity, we must get rid of the notion of attracting poles. We have seen chemical action produce electric currents, and electric currents chemical action. These polarities are believed to be but different phases of the same principle.

**393. Chemical and Crystalline Polarities.**—It is evident there is a very close connection between chemical affinity and the attraction which arranges together the particles of a crystal. Chemical affinity takes the elements out of solution, and places them in a fixed polar arrangement (106). The force which draws

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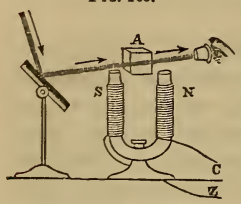
is the essence of polarity? 391. What was long suspected concerning the magnetic and electric forces? Why are they now considered to be due to the same cause? 392. How is the chemical shown to be a polar force? What is the teaching of FARADAY concerning it? What relation exists between chemical attraction and electric currents? 393. What is said of chemical affinity and crys-

the particles together, and that which places them in a crystalline order, are evidently one.

**394. Crystalline and Optical Polarity.**—Here also is a most intimate and beautiful connection. We have seen that crystals are used for polarizing light, but this power depends upon the axis of the crystal; that is, the direction of the polarities of the crystalline particles. It has also been observed that the action of heat and electricity upon bodies is influenced by the polarity of their atoms (267).

**395. Magnetism and Light.**—A beautiful illustration of these connections was discovered by FARADAY, in 1845. A piece of flint glass, A, Fig. 165, is placed between the poles N S of a powerful electro-magnet, and a ray of light, polarized in a vertical plane by reflection from a piece of blackened glass, passes through the glass A, and is viewed through a piece of Iceland spar (*Nicol's prism*). So long as the bars N and S are not magnetic, the ray is passed or stopped as usual by revolving the prism. If now it be turned, so that the *ray is darkened*, and the wires C and Z are connected with the battery, the bar is made magnetic, it affects the glass, and the ray instantly becomes visible. A chain of four polarities, electric, magnetic, luminous, and crystalline, is called into action in producing this remarkable effect. If we add the organic polarity of the nerve of vision, we have a fifth link of the polar series.

FIG. 165.




Magnetism and Light.

**396. Optical and Thermal Polarities.**—It only remains now to state that heat is capable of being polarized like light to complete the mysterious chain of influences which shows that there is some common principle of action among these forces, and a deeper unity of cause than was formerly suspected.

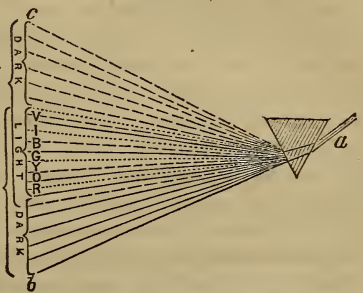
## § II. *Connection of the Radiant Forces.*

**397.** The intimate connection of the radiant forces has been before referred to, but requires further illustration. Fig. 166

tallization? 394. Upon what does the power of the crystal to polarize light depend? 395. What is the connection between magnetism and light? Describe the experiment, Fig. 165. What polarities are here called into play? 396. What is said of

represents the contents of a luminous beam $a$, spread out by the prism from $b$ to $c$. The heating effects begin at $b$, and extend through the space embraced by the thermal bracket, varying in intensity and quality at each point. The differences among the thermal rays so much resemble those of color, that MELLONI designated this phenomenon as the 'ideal coloration of heat.' The middle bracket of the diagram gives us a scale of radiations which produces the world of colors, while the chemical bracket comprehends a wide range of chemical intensities which take effect upon different compounds in the different spaces. The continuous lines indicate heat rays; the broken lines, chemical rays; and the dotted lines, luminous rays.

FIG. 166.




Distribution of the Forces of the Spectrum.

**398. Identity of Heat and Light Motions.**—It has been said that all these radiations obey precisely the same laws of movement; but the analogies of heat with light are carried much farther than has yet been stated. Not only has the interference of heat been proved, but no change or manifestation can be impressed upon light that does not affect the associated heat in the same manner and degree. The heat ray undergoes double refraction by Iceland spar, and the two separated beams are polarized in planes at right angles to each other (359). The phenomenon of the *magnetic rotary polarization of heat* has also been observed. These facts show beyond question that heat cannot be a material substance, but is a mode of motion of the same nature as light.

**399. Dr. Draper's Experiment.**—Still more conclusive on this point are the beautiful experiments of Prof. DRAPER. He subjected various substances, under suitable circumstances for observation, to the action of heat, and found the order of effects

heat? What does this show? 397. What does Fig. 166 represent? How does MELLONI regard the differences among the heat rays? What does the highest bracket in Fig. 166 include? 398. In what additional respects does heat resemble light? 399. What is observed at the commencement of DRAPER'S experiment?

strictly dependent upon the energy of the combustion, or source of heat. At the commencement of the action, as the body begins to be heated, the rays emitted are of the lowest refrangibility, being but slightly refracted by a prism of rock salt. As the molecular action of combustion increases, the refrangibility and intensity of the heat rays increase. At about 1000°, the emitted rays become so energetic that they begin to act upon the eye, producing the sensation of a dull red light, and this effect takes place at the same thermometric degree with all solids. As the temperature ascends, the colors of the spectrum appear in the order of their refrangibility; red, orange, yellow, green, blue, indigo, and violet. At 2130° all the colors are produced, and from their commixture the substance appears *white hot;* actinic effects then appear in full intensity. As the body cools, the order of effects is reversed, and the colors disappear successively, from the violet to the red.

**400. How Heat and Light Differ.**—The foregoing experiment proves that all the diversified effects of the spectrum are due to *one energy.* Heat and light are not the same thing, but they have one cause. Heat rays differ from light rays simply as one color differs from another. It is well known that the selfsame force produces widely different effects according as it acts upon different media. The same electric current, if sent through a thin wire, produces *heat;* if sent round a piece of iron, produces *magnetism;* and if through a conducting liquid, *chemical decomposition.* So, the same agent, acting upon different organs of the body, affects our consciousness differently;—falling upon the nerves of feeling, it excites the sensation of heat; and upon the nerves of seeing, the sensation of sight.

**401. Fluorescence—Dark Rays changed to Light.**—The conversion of one radiant force into another, and the influence of the body upon which it acts, are strikingly exemplified by a discovery of Prof. STOKES. He filled a glass tube with a solution of sulphate of quinine, and then moved it through the spectrum, entering at the red ray. No unusual effect was produced till it passed the extremity of the violet, and entered the region of the chemical rays, when 'a ghostly gleam of pale blue light shot across the

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As the action becomes more intense, what follows? What results when the body cools? 400. What does this experiment prove? How does heat differ from light? How does the electric current produce different effects? How may the same agent produce different sensations? 401. Describe the experiment of Prof. STOKES.

tube.' The dark chemical force was *changed to light* by the quinine solution. Thus the same force acting upon one surface, produces one effect, and upon another, an opposite one. Various substances give rise to this result, as a decoction of horse chestnuts, glass stained with oxide of uranium, &c. They have the property of receiving rays of one refrangibility, and emitting them at a lower one; and, as the colors of the spectrum are similarly lowered in the scale of refrangibility by these substances, the phenomenon was first known as the *degradation of light*. The term *fluorescence* is now applied to it, because it is very strongly manifested by a body known as *fluor spar*.

## § III. *Conservation of Force.*

402. We have referred to the great truth that force, like matter, is persistent and indestructible: its changes are but mutations from form to form; an impulse of force can no more be created or destroyed than a particle of matter. This principle is known as the *conservation of force*, and is characterized by Dr. FARADAY as 'the highest law in physical science which our faculties permit us to perceive.' The phrase *correlation of forces* has been used to indicate their mutual convertibility, but both forms of expression imply the same great principle.

403. **History.**—This is but another case, of which the history of science furnishes so many, where a great discovery belongs rather to an epoch than to an individual. In the growth of scientific thought, the time had come for the evolution of this principle, and accordingly several master minds seized upon it independently about the same time. Among these are MAYER and HELMHOLTZ, of Germany, COLDING, of Denmark, and JOULE, GROVE, and FARADAY, of England. These discoverers announced their results between 1840 and 1850; they became generally known during the next ten years, and are now established as comprehensive and guiding principles of science.

404. **Origin of the Idea of Perpetual Motion.**—To common

What was the effect? What other substances manifest this property? How were the phenomena first known? What are they termed now, and why? 402. What is the conservation of force? How is it characterized by FARADAY? What is the correlation of forces? 403. What is said concerning its discovery? To whom does it belong? What was done between 1840 and 1850? Between 1850 and 1860?

observation, when a moving body comes to rest, its force is annihilated, and this has been generally believed. The notion that force might thus pass out of existence—from something to nothing naturally led to the corresponding idea that it might be *created*, or come *from* nothing. These loose conceptions of force gave rise to the fallacy of a perpetual motion—a machine that could go on forever, producing its own power, with no external supply of force.

**405. Persistence of Mechanical Force.**—This error was first detected in mechanics. It was found that machines do not create force, but only communicate, distribute, and apply that which is imparted to them. In all cases, the force expended is exactly measured by the resistance overcome. In the case of water power, to lift a hammer of 100 pounds, 1 foot high, at least 100 pounds of water must fall through 1 foot; or, what is the same thing, 200 pounds must fall through $\frac{1}{2}$ a foot, or 50 pounds through 2 feet. If a hammer weighing 1,000 lbs. is employed, with the same driving force it will either be raised to only $\frac{1}{10}$ the height, or tenfold the time will be required to raise it to the same height. Thus, in mechanics, a certain amount of power or change acting as *cause* produces an exactly equal amount of change as *effect*.

**406. Convertibility of the Forces.**—Now what occurs here is but the consequence of a universal law which applies to all kinds of physical energy. The preceding pages have afforded numerous illustrations of the production of one force by another. Heat, we have seen, excites electricity, and through that magnetism, chemical action, and light. Or, if we start with magnetism, this may give rise to electricity, and this again to heat, chemical action, and light. So, chemical action produces heat, light, and electricity; and it has been also found that *a mere line of decomposing particles* manifests a direct magnetic influence. That electricity sets the whole series in action is strikingly exemplified by electrifying the *sulphuret* of *calcium*, or some similar substance. At the instant of electrization, it becomes *magnetic;* is *heated*, and, if the electricity be sufficiently intense, it becomes luminous; that is, *light* is produced. It expands, therefore there is *motion;* and is decomposed—hence there is *chemical action*.

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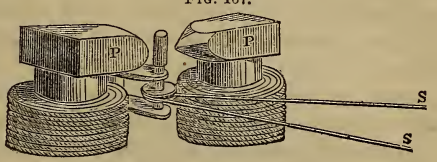
404. What is the origin of the idea of perpetual motion? 405. What was found in regard to machines? What is the relation between lifting a hammer and the descent of water? 406. What forces may be produced by heat? What examples

**407. 'Friction against Space.'**—A new and remarkable illustration of the effect of resistance to motion in producing heat has been lately discovered. If a blade of copper or any conductor be moved backward and forward between the poles of an active and powerful electro-magnet, although it touches nothing, it will be resisted as if it were sawing through cheese, and become hot. A copper cylinder filled with alloy, and mounted between the poles, P P, Fig. 167, seems grasped by an invisible hand. If rapidly spun around by the string s s, attached to a wheel, it will grow hot, and, in three minutes, the alloy will be melted; indeed the copper cylinder may be made red hot. The heat produced is in precise proportion to the force expended in increasing the resistance.

FIG. 167.




Magnetism resisting Motion.

**408. Grove's Experiment.**—In a very beautiful experiment, Mr. GROVE produced the whole circle of forces by using light as the exciter. He inclosed a sensitive daguerreotype plate in a box having a glass front with a shutter over it. Between this glass and the plate was a gridiron of silver wire. The daguerreotype plate was connected with one extremity of a galvanometer coil, and the wire gridiron with a BREGUET'S thermometer;* this and the galvanometer being also connected, so as to form a complete circuit. When the shutter was raised and a beam of light admitted, *chemical action* was produced in the plate; *electricity* in the wires; *heat* in BREGUET'S helix; *magnetism* in the coil, and *motion* in the galvanometer needles.

**409. Forces Convertible in Definite Quantities.**—These transmutations take place in definite quantities. It is well understood

* BREGUET'S *thermometer* consists of a vertical helix compounded of two ribbons of different metals. The slightest amount of heat, by causing unequal expansion of the two metals (238), uncoils the spiral and produces motion, which is indicated by a horizontal needle passing over a scale.

are given of forces producing each other? What is the effect of electrifying the sulphuret of calcium? 407. What is the effect of sawing a piece of copper back and forth between the poles of an electro-magnet? Describe the experiment, Fig. 167. 408. What is shown by GROVE'S experiment? 409. What is the

that a certain amount of fuel is necessary to perform a given amount of work with a steam engine. This means strictly that a definite quantity of the chemical action of combustion gives rise to a fixed quantity of heat, and this to a determinate quantity of mechanical effect. Dr. FARADAY made the important discovery of the definite chemical effect of the voltaic current. He found that an equivalent of an element consumed in a battery gives rise to a definite quantity of electricity, which will produce exactly an equivalent of chemical decomposition. For example, the consumption of 32 grains of zinc in the battery, excites a current which will set free from combination 1 grain of hydrogen, 104 of lead, 108 of silver, 39 of potassium, and 31.6 of copper. These are the combining numbers of those elements, and establish a remarkable equivalency between chemical and electrical forces.

**410. Atomic Heat.**—The definite relation between combining numbers and specific heats is equally remarkable. For example, 28, 32, 103 are the atomic numbers of iron, copper, and lead; but they also express the relations of these bodies to heat. They indicate the exact quantities of the metals which will be raised through equal temperature by equal sources of heat. It would take the same amount of burning alcohol to heat 28 lbs. of iron 100° that would be consumed in raising 32 lbs. of copper or 103 of lead through the same number of degrees. The correspondence is very close with the other metallic elements and with sulphur, while the atomic heat of several of the elements is *double* that of the bodies mentioned.

**411. Units of Heat and Force.**—To ascertain at what rate mechanical force produces heat, requires certain standards of comparison, known as the *units of heat and force*. The English unit of heat is 1 lb. of water raised through 1 degree of Fahrenheit; the unit of force is 1 avoirdupois pound falling through 1 foot of space; or, as it is called, the *foot-pound*. 100 lbs. of water raised through 10°, would require 1,000 units of heat; while 100 lbs. falling through 10 feet would produce 1,000 units of force.

**412. The Mechanical Equivalent of Heat.**—To Dr. JOULE, of Manchester, England, is due the honor of having experimentally

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relation between fuel, heat, and work? What did FARADAY find to be the relation between chemical action and electricity? Examples. 410. What is said of the relation between combining numbers and specific heats? Examples. 411. What are the units of heat and force? 412. Who determined the mechanical

demonstrated *the mechanical equivalent of heat;*—that is, how many units of force are equal to a unit of heat. He agitated water, mercury, and oil successively, in suitable vessels, by means of paddles driven by falling weights, and determined the exact amount of force spent, and of heat produced. He also rubbed cast iron discs against each other, carefully measuring the force employed and the resulting heat. By varied and repeated experiments he found that the same expenditure of power produced the same absolute amount of heat, *whatever materials were used;* and that a pound weight falling through 772 feet, or 772 lbs. falling through 1 foot, and then arrested, produce sufficient heat to raise 1 lb. of water 1°; so that the unit of heat is equal to 772 units of force. This is known as 'JOULE's Law.'*

**413. Further Links of the Dynamic Chain.**—The law of equivalence between mechanical energy and heat thus directly established is beautifully confirmed by introducing other links of force. An electric current, which, by resistance in passing through an imperfect conductor, produces sufficient heat to raise 1 lb. of water 1 degree, sets free an amount of hydrogen which, when burned, raises exactly 1 lb. of water 1 degree. And again, the same amount of electricity will produce an attractive magnetic force by which a weight of 772 lbs. may be raised 1 foot high.

**414. Significance of Joule's Law.**—The establishment of the

* It is worth while here to note that the first step in these grand views of the forces which have been recently unfolded, was taken toward the close of the last century by an American, BENJAMIN THOMPSON, afterward known as Count RUMFORD. He went to Europe in the time of the revolution, and, devoting himself to scientific investigations, became the founder of the Royal Institution of England. He exploded the notion of caloric, demonstrated experimentally the conversion of mechanical force into heat, and arrived at quantitative results which, considering the roughness of his experiments, are remarkably near the established facts. He revolved a brass cannon against a steel borer by horse power for 2½ hours, and generated heat enough to raise 18¾ lbs. of water from 60° to 212°. He explicitly announced the view now held of the nature of heat, and wrote as follows, the italics being his own: 'What is heat? Is there any such thing as an *igneous fluid?* Is there any thing that with propriety can be called caloric? We have seen that a very considerable quantity of heat may be excited by the friction of two metallic surfaces, and given off in a constant stream or flux in *all directions* without interruption or intermission, and without any signs of *diminution* or *exhaustion.* In reasoning on this subject we must not forget that *most remarkable circumstance,* that the source of the heat generated by friction in these experiments appeared to be *inexhaustible.* It is hardly necessary to add that any thing which any insulated body or system of bodies can continue to furnish *without limitation,* cannot possibly be a *material substance;* and it appears to me to be extremely difficult, if not quite impossible, to form any distinct idea of any thing capable of being excited and communicated in these experiments, except it be MOTION.'

equivalent of heat? What is it? How was it ascertained? What is JOULE's law? 413. How is the law of equivalence between mechanical energy and heat

principle of correlation between mechanical force and heat constitutes one of the most important events in the progress of science. It teaches us that the movements we see around us are not spontaneous, or independent occurrences, but links in the eternal chain of forces: that when bodies are put in motion, it is at the expense of some previously existing energy, and that when they come to rest, their force is not destroyed, but lives on in other forms. Every motion we see has its thermal value; and when it ceases, its equivalent of heat is an invariable result. Should the motion of the heavenly bodies be arrested, it would produce a conflagration of the universe.

**415.** As the motions and masses of the planetary bodies are definite and determined, we can predict the exact consequence if those motions should cease. The earth is 8,000 miles in diameter, 5½ times heavier than water, and moves through its orbit at the rate of 68,000 miles an hour. Were its motion suddenly arrested it would generate a heat equal to the combustion of 14 globes of anthracite coal as large as the earth. Should it fall into the sun the shock would produce a heat equal to the combustion of 5,400 earth-globes of solid coal. If the sun were a solid mass of anthracite his combustion would maintain the present heat but 5,000 years; whereas, if the planet, Jupiter, should fall into the sun it would produce heat enough to maintain the solar emission *for* 35,000 *years* (1196).

**416.** If a fragment of coal were taken to the sun and burned it would give out a definite amount of heat, but if it should fall from the earth to the sun it would produce 3,000 times more heat by its arrested motion. It has been suggested that meteoric matter falling into the sun may be the actual cause of his heat.

**417. Motion alone convertible.**—As two substances when combined chemically, produce heat, and *remain combined*, it may be asked, 'How can the heat be regarded as converted chemical force, while that force is still in action?' This will be understood by referring to the case of gravity. When a lifted body falls, it gives back the force expended in lifting it, but gravity still attracts it to the earth with undiminished force. So with the chemical

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confirmed? 414. What does this principle teach us? What would result if the movement of the heavenly bodies should be arrested? 415. What if the earth's motion were suddenly stopped? Mention some further facts in this connection. 416. What is said of a fragment of coal? 417. How can the heat be converted into

atoms. They are detached, and then rush together again, giving back a force equal to that employed in separating them; but they remain combined as the weight remains pressed to the ground. Neither gravity nor affinity are for an instant *suspended*; they are in constant action and are only *resisted* by antagonist forces: the *amount of motion* which results from this resistance measures the convertible force. Only force in action—which is known as living force, or *vis viva*—is convertible.

**418. Relations of Matter and Force.**—In the study of nature, questions of force are becoming more and more prominent. The things to be explained are *changes*—active effects—motions in ordinary matter, and the tendency is to regard matter, not as *acted upon*, but as in itself inherently active. The chief use of atoms is to serve as points or vehicles of *motion*. Thus the study of matter resolves itself into the study of forces. Inert objects, as they appear to the eye of sense, are replaced by activities revealed to the eye of intellect. The conceptions of 'gross,' 'corrupt,' 'brute matter,' are passing away with the prejudices of the past, and in place of a dead material world, we have a living organism of spiritual energies.

**419.** The principle of the correlation of forces is one of the most fruitful and far-reaching that science has established. Its introduction forms one of those intellectual epochs which change the standpoint of the philosopher, revealing old questions in new aspects, and bringing many new ones into view. It teaches with a new emphasis the great lesson of the unity of the universe, and the brotherhood of the agencies through which it is governed. And as the policy of the Divine Administration is *one*, there can be no doubt that the principle applies not only to physical forces, but to *all* forces. Its operation has been traced, as we shall see, in the field of organization, and it opens a new and promising method of studying the various activities of human society.

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chemical force while that force is still in action? 418. What are to be regarded in studying nature? State the chief use of atoms. What is said of force and matter? 419. Of the principle of the correlation of the forces?

# PART II.

# INORGANIC CHEMISTRY.

## ORIGIN OF THE SCIENCE—ALCHEMY.

**420. The Four Ancient Elements.**—Thoughtful minds, as we have previously stated, never rest satisfied with *appearances;* they always seek for *reasons* and *causes.* This was the case in the most ancient times in regard to the objects of nature. They were held to be, not what they seemed, but formed of various commixtures of four elements, fire, air, earth, and water, and for thousands of years the properties and changes of all substances, animate and inanimate, were explained on this hypothesis.

**421.** This view was not without its philosophy. All bodies, it was said, must be either hot or cold, moist or dry. These are fundamental properties, and their various unions produce the four elements thus:

| *Dryness and Warmth produce* | *Warmth and Moisture—* | *Moisture and Cold—* | *Dryness and Cold—* |
|---|---|---|---|
| Fire; | Air; | Water; | Earth. |

These elements fire, air, earth, and water, may be transmuted into each other by exchange of properties. Thus, if cold is added to air it destroys the warmth and converts it into water: by the substitution of dryness for moisture, water is transformed into earth; while, by reversing these changes, earth becomes water, and water, air. Thus, by the *communication of properties*, all things were supposed to be produced, the predominating element giving character to the body.

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prejudices are passing away? 420. How were the objects of nature regarded in ancient times? 421. How were these elements produced? How transmuted?

**422. The Foundation of Alchemy.**—The leading idea of the doctrine of the four elements was the *instability of the properties of matter.* They were held to be like clothes which are put on and off at will—mere shifting and communicable things, the addition or subtraction of which transformed one substance into another. Water was poured upon quick lime; it disappeared and was *transmuted;* that is, it lost the properties of water, and acquired those of stone. A small plant in a weighed portion of soil, by the addition of pure water only, grew into a vigorous shrub, increasing many pounds in weight, while the soil lost but a trifle. What more natural, therefore, than to suppose that water was 'transmuted' into a living structure. This ancient and deeply established belief was the starting point of the labors of the alchemists, who were the earliest chemists.

**423.** For centuries, philosophy had taught that the properties of matter are transferable; 'then,' said the alchemists, 'let us transfer to lead and iron the properties of gold!' All bodies having a metallic lustre and appearance, they naturally regarded as metals; such as preserved this lustre when exposed to fire, were called *noble*, or *perfect* metals, while those which lost their lustre and malleability by heat were termed *base* metals. The metals were, moreover, regarded as compounds consisting of opposite elements, one of which made them pure, and the other base, their rank being determined by the relative proportions of these elements.

**424. Plausibility of the Idea.**—Nor were these views mere idle speculations; they seemed strongly supported by facts. The alchemists saw that the lead ore—*galena*, had the metallic lustre and color of lead; they, therefore, believed it to be a real metal. But, if heated, it gave off sulphur, while, at the same time, all its metallic properties—lustre, malleability, and fusibility—were heightened, and it became true lead, or a more perfect metal. What more reasonable than to suppose, that by the separation of a little *more* sulphur, it might be still further purified, and changed to silver? And when, on further application of heat, a certain amount of silver *was actually obtained* from the lead, and from this silver a trace also of gold, it was not surprising that the

422. What was the leading idea of this philosophy? What common phenomena were interpreted as instances of transmutation? What did the alchemists propose? What bodies were called metals? How were they divided? What was their composition? 424. By what experiments and reasoning did they sustain the

alchemist should honestly believe that he had *created* the three metals, and that by perfecting the operation, he could convert *all* his galena into gold.

425. Again, the alchemists knew that the brilliant metal mercury volatilizes by heat and disappears in invisible vapor. Hence when a base metal lost its lustre in the fire, or rusted in the air, they supposed it was caused by the escape of the volatile mercury, which they regarded as the pure metallic principle. Thus, by diminishing their sulphur and increasing their mercury, the alchemists expected to finally perfect or ennoble all the base metals;—that is, turn them into gold. The wondrous substance which should have the power of expelling the sulphur, fixing the mercury, and thus accomplishing transmutation, was universally believed in and sought for under the name of the *Philosopher's Stone.*

426. The alchemists, moreover, drew support for their belief from all imaginable sources. The metals were held to grow like plants, and the philosopher's stone was, therefore, the seed of gold. They said also, 'Does not fermentation transmute the sweet juices of plants into the invigorating and youth-giving water of life (aqua vitæ, alcohol)? Does not digestion transform food into blood?' In a decree of 1423, HENRY VI., of England, declared 'that the clergy should engage in the search for the philosopher's stone, for since they could change bread and wine into the body and blood of Christ, they must also by the help of God succeed in transmuting the baser metals into gold.'

427. But the doctrine was carried much farther. If the metals might be thus transformed, what should limit the magical power of the transforming agent! Other transmutations were equally possible, as that of weakness, pain, and disease into robust and perennial health, and thus the marvellous stone became also a *universal medicine:* or it might even change the decrepitude of old age back to the vigor and fire of youth, and thus become the *elixir of life.*

428. **Motives of the Alchemists.**—We can now comprehend the power of the ruling motive that first drove men to investigation. The love of knowledge and the desire to explore the secrets

idea? 425. What was the philosopher's stone? 426. What other common changes gave support to the belief? 427. What led to the search for a universal medicine and the elixir of life? 428. Why was alchemy necessary? 429. What instances are given

of nature in quest of truth, were not sufficiently strong incentives in those days of darkness and ignorance. A mighty incitement was required that should rouse the most powerful passions of human nature, and this was providentially furnished by the belief in the philosopher's stone. Its possession would secure all the conditions of earthly happiness—boundless wealth, perpetual health, eternal youth!—and for these ineffable prizes the alchemists labored day and night, devising experiments, inventing processes, ransacking nature in a thousand directions, and putting her to every conceivable torture to wring out the wondrous secret. The object sought was not attained, but the foundations of chemistry were laid. Men working in the direction of an illusive purpose made many discoveries which they could not appreciate, but which were invaluable to the world.

**429. Results of their Labors.**—For example, a cobbler of Bologna, named Cascariolo, who divided his time between shoemending and alchemy, discovered in one of his rambles a heavy stone now known as the *sulphate of baryta.* In experimenting with it he obtained, instead of gold, a most extraordinary substance—'a light magnet,' 'which absorbed the rays of the sun by day to emit them by night.' The cobbler was in ecstasy; if the strange body could absorb the golden light of the sun, it might surely convert the base metals into gold—the *sol* of the alchemists. Thus was discovered the *sulphuret of barium*, the first substance known to become phosphorescent by solar action. Again, an alchemist in Hamburg, named Brandt, long baffled in the search for the philosopher's stone, reflecting one day on the yellow color of urine, suspected that it might contain some gold-engendering principle. He began experimenting, and, after years of toil, at length discovered, not gold, but phosphorus! In the same way, the alchemists sought for the *alcahest*—the liquid that should dissolve all things; they failed, but discovered those powerful solvents—sulphuric, nitric, and muriatic acids, which have largely contributed to the arts of civilization. So the search for the *elixir of life* revealed many precious substances for the alleviation of suffering and the increase of human enjoyment.

**430. Vitality of their Idea.**—The power and persistence of the fundamental idea of the alchemists are surprising. It was only

where the search ended in discovery? 430. What is said of the persistence of this belief? 431. How must alchemy be interpreted? What is its relation to chem-

near the close of the last century that the ancient belief in the transmutation of the elements was finally overthrown; and we can now hardly conceive how deeply it was interwoven with universal thought. The great French chemist LAVOISIER gave a course of public lectures with elaborate experiments to show that water could not be transmuted into earth; while an Italian philosopher went carefully into the proof that water from melted Alpine snows was of the same nature as that from common springs and wells.

**431.** Alchemy, it is well known, was mixed up with magic, astrology, and various gross impostures, yet those who denounce it as utterly visionary and absurd, profoundly misread this chapter of man's mental history. Alchemy formed a natural stage in the growth of the human mind, and must be interpreted in connection with its period. It was the offspring of the old philosophy, but the parent of modern chemistry, and must always have a memorable interest as the first experimental grapple of man with nature.

## CHAPTER VII.

### THE ATMOSPHERIC ELEMENTS.

### (ORGANOGENS.)

**432. Inorganic Chemistry** is that branch of the science which treats of the properties of the chemical elements, and of the compounds they form, independent of the influence of life.

**433. Classification of the Elements.**—The simple bodies are divided into two classes, *metals* and *metalloids*, or non-metallic elements. This general distinction is obvious and useful, but it corresponds to no clear line in nature, as the elements pass into each other gradually, two or three being ranked by some as metals, and by others as metalloids.

**434.** We first consider these four remarkable elements, Oxygen, Hydrogen, Nitrogen, and Carbon, which have the leading

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istry? 432. What is inorganic chemistry? 433. How are the simple bodies divided? Why is this distinction faulty? 434. What elements do we first con-

share in the world's economy. They form the atmosphere, and are, therefore, termed the *Atmospheric Group*. They are, also, the chief constituents of the vegetable and animal world, and are hence called *Organogens*—generators of organization. Next come Chlorine, Iodine, Bromine, and Fluorine, bodies which combine with metals forming saline compounds, of which common salt is a type, and hence called by BERZELIUS, *Halogens*, or salt formers. Sulphur, Phosphorus, Selenium, and Tellurium form a combustible group termed *Pyrogens*, or fire producers. Lastly, Silicon and Boron are associated together as *Hyalogens*, or glass formers.

## § I. *Oxygen.*

*Symbol*, O. *Equivalent*, 8. *Specific Gravity*, 1.1087.

**435.** We begin the study of chemical substances with that most remarkable and important element, *oxygen gas*. The word *gas*, which is applied to thin vaporous bodies like air, was first used in the seventeenth century, and is an interesting memorial of the state of mind out of which the science of chemistry grew. It had been observed that strange things occurred in certain mysterious places, as churchyards, caves, and the bottoms of mines and wells;—there were lurid flames and sulphurous fumes, violent explosions, and sudden death. These were supposed to be the work of *invisible spirits*. In the operations of alchemy, vessels would often explode with danger to those around, and this also was attributed to the vexed and imprisoned spirits who thus avenged themselves upon their tormentors. 'The devout alchemists, therefore, commenced their experiments with prayer, and stamped upon their vessels the mark of the holy cross;—hence the name *crucible*.' To these invisible agents, VAN HELMONT first applied the term *gas*, from *gahst* or *geist*, a ghost or spirit. The terms spirit of wine, spirit of nitre, &c., are also significant of the superstitions of those early times.

**436. Discovery of Oxygen.**—This gas was discovered by Dr. PRIESTLEY, of England, in 1774, and rediscovered in the following year by the Swedish chemist, SCHEELE. Its discovery is also claimed by the French chemist, LAVOISIER. There was a beautiful

sider? What are they called, and why? How are the remaining metalloids grouped? 435. What is a gas? Whence is the term derived? Origin of the term *crucible*? 436. When and by whom was oxygen discovered? What is said of the

significance in the form of PRIESTLEY's celebrated experiment. He submitted one of the compounds of mercury to the rays of the sun, concentrated by a burning-glass, when oxygen was set free. It was fitting that the sun, who, by his chemical relation to oxygen, controls the destiny of the living world, should himself first summon this wonderful agent into the conscious presence of man.

**437. Its Importance.**—This has been justly pronounced the capital discovery of the last century, rivalling in importance the great discovery of gravitation, by NEWTON, in the preceding century. It formed one of the great eras in the progress of human knowledge; it put an end to old theories, laid the foundation of modern chemical science, and furnished the master key by which man has been enabled to open the mysteries of nature. But while the discovery of gravitation is unsurpassed in grandeur, that of oxygen is far more vitally linked with the course of earthly affairs.

438. Of its vast practical consequences, Prof. LIEBIG observes: 'Since the discovery of oxygen, the civilized world has undergone a revolution in manners and customs. The knowledge of the composition of the atmosphere, of the solid crust of the earth, of water, and of their influence upon the life of plants and animals, was linked with that discovery. The successful pursuit of innumerable trades and manufactures, the profitable separation of metals from their ores, also stand in the closest connection therewith. It may well be said that the material prosperity of empires has increased manifold since the time oxygen became known, and the fortune of every individual has been augmented in proportion.'

**439. Preparation.**—Oxygen may be procured in many ways. To obtain a large supply, we may heat to redness black oxide of manganese in an iron bottle, fitted with a delivering tube through which the liberated gas escapes. A pound of this oxide usually yields about 1,400 cubic inches of impure gas. The chemical changes which take place may be thus expressed in symbols:—

$$3Mn\,O_2, \text{ give } Mn\,O, Mn_2\,O_3 + 2O:$$

that is, the peroxide of manganese is changed to two other compounds, and loses one third of its oxygen in the process.

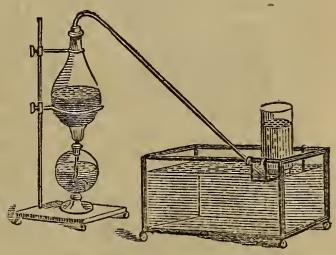
**440. By a New Process.**—It has lately been found that by

discovery? How did PRIESTLEY make the discovery? 438. What does Prof. LIEBIG say of it? 439. What is the common method of obtaining oxygen? What

mixing nitrate of soda, NaO, $NO_5$, with crude oxide of zinc, ZnO, in the proportion of 10 lbs. of the former to 20 lbs. of the latter, and heating them to redness in an iron retort, a large amount of oxygen is rapidly given off, diluted with about 40 per cent. of nitrogen. The mixed product contains about three times as much oxygen as the air, and may prove valuable for some heating and illuminating purposes, as its cost is said to be but one fifth that of oxygen by any other process.

**441. From Chlorate of Potash.**—It can be obtained still more pure, and very readily from chlorate of potash. Two or three hundred grains of the salt are placed in a glass retort, which is fitted tightly with a cork containing a glass tube, bent so as to dip under the shelf of the pneumatic trough, Fig. 168. The retort is heated, and the chlorate gives off more than a third of its weight of gas, an ounce furnishing nearly two gallons. This salt consists of chloric acid and potash, and in the change chloride of potassium is formed, the whole of the oxygen being disengaged—thus

Fig. 168.



Making Oxygen.

$$KO,ClO_5 = KCl + 6O.$$

The decomposition of the chlorate is much facilitated by mixing with it one fourth its weight of oxide of copper, or black oxide of manganese thoroughly dried. These substances take no active part in the change, but seem to aid the decomposition by simple presence (catalysis).

**442. The Pneumatic Trough** is a vessel by means of which gases are collected. It is usually filled with water, just under the surface of which there is a perforated shelf for the support of jars, Fig. 168. The jar, filled with water, and inverted, is lifted nearly out of the liquid, and slid upon the shelf; the water being supported above its level by atmospheric pressure (563). A con-

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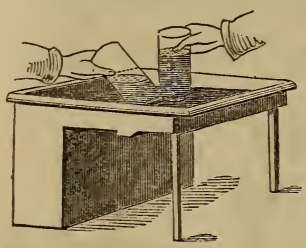
is the chemical change? 440. Describe the new process? For what may it perhaps be used? 441. How is it obtained from chlorate of potash? Explain the re-action. How may the change be facilitated? 442. Describe the pneumatic

veying tube bends under the shelf, from which the delivered gas rises into the jar, displacing the water. It may be then slid off, mouth downward, into a shallow vessel, containing a little water, and kept for use. In Fig. 168, the trough is represented as having glass sides which are very convenient for showing effects in the lecture room. The best form is that of a cistern, Fig. 169, so deep that jars may be conveniently inverted in it, and with a large shelf for holding several of them. Gases may be transferred from one vessel to another by *pouring them upward*, as shown in Fig. 169. The vessel to be filled with gas is first filled with water, inverted, and its mouth raised nearly to the surface of the liquid. The mouth of the vessel containing the gas is then brought under the other by gentle inclination, and the gas rises in bubbles, displacing the water, and filling the second jar.

Fig. 169.



Pneumatic Trough.

**443. Physical Properties of Oxygen.**—Oxygen is a transparent, colorless, tasteless, inodorous gas, about $\frac{1}{10}$ heavier than the atmosphere, and forming 23 per cent. of its weight. It refracts light the least of any known substance, and has never been condensed into a liquid. It possesses weak magnetic properties, but loses them at a high temperature. The magnetic effect of atmospheric oxygen has been estimated as equal to a film of iron covering the earth $\frac{1}{230}$ of an inch in thickness, and, as this property varies with the daily temperature, it is supposed that it may be concerned in the diurnal fluctuations of the needle. Oxygen is slightly soluble in water, 100 gallons of which absorb about $4\frac{1}{2}$ of the gas.

**444. Its Chemical Properties.**—Oxygen is perfectly neutral, possessing neither acid nor alkaline qualities; but, though mild and bland and apparently the very type of passiveness, this substance is endowed with the most extraordinary power. Its attractions are the most intense and varied of all the elements. So remarkable is

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trough. How is it used? What is the best form? How is pouring upward effected? 443. What are the physical properties of oxygen? Its magnetic effect in the atmosphere? To what degree is it soluble? 444. What are its chemical

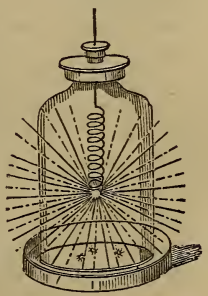
its adaptive power that it combines with every one of the simple bodies (except, perhaps, fluorine), giving rise to compounds of the most opposite and diverse properties. A glance at the chemical chart shows the wide range of its affinities. With some elements it forms gases, with others liquids, and with others solids. Some it holds so slightly that they are readily separated, and others it seizes with such power that the utmost skill of the chemist is tasked to force them asunder. Uniting with one set of bodies, it gives rise to neutral compounds, with another to corrosive acids, with another to burning alkalies. With some elements it forms nourishing food, with others deadly poisons; mingled with an invisible body like itself, it forms the air we breathe, and united with another twenty times lighter and rarer than itself, it produces the water we drink.

Fig. 170.

Taper in Oxygen.

**445.** The oxygen of the air (about one fifth of its weight), is equally diffused throughout it, and exists in a free or uncombined condition. All combustion in the open air is the result of the action of oxygen. It has a powerful affinity for the elements of which fuel is composed, and unites with them with such violence as to give rise to the heat and light of our ordinary fires, as we shall see in Combustion (588.)

Fig. 171.



Combustion of Iron in Oxygen.

**446. Combustion in Oxygen.**—All substances which burn in air, burn in pure oxygen with greatly increased brilliancy. If the flame of a taper, Fig. 170, be extinguished, and a single spark remain upon the wick, on plunging it into a jar of pure oxygen, it will be re-lit and burn with extreme vividness; and this may be repeated many times in the same vessel of gas. The combustion of a splinter of wood is brilliant, and a piece of bark charcoal glows and scintillates in the most beautiful manner.

**447.** Substances usually considered in-

properties? What extraordinary power does it possess? A glance at the chart shows what? Give examples. 445. In what state does oxygen exist in the air? What is its office in combustion? 446. Describe the experiment, Fig. 170?

combustible also burn violently in oxygen. If a piece of fine iron wire (or, better still, a steel watch spring) be coiled into a spiral and then tipped with sulphur, ignited and introduced into a jar of oxygen, it burns with dazzling brilliancy and splendid corruscations, Fig. 171. Occasionally globules of white-hot iron fuse into the glass even through an inch depth of water.

**448.** If a jar of oxygen be inverted over a stand upon which there is a little burning sulphur, a beautiful blue light is emitted, and the fumes produced circulate round in curious rings, Fig. 172. If phosphorus be burned in the same manner, a blinding flood of light is produced, accompanied with great heat. In all these cases, the effects are simply due to the union of oxygen with the burning body, and could we have weighed them before the experiment, and the products of combustion afterward, they would have been found precisely equal.

Fig. 172.

Burning of Sulphur.

Fig. 173.

Phosphorus burning in Oxygen.

**449. Slow Oxidation.**—The combustion of oxygen with the elements is called *oxidation*, and the products *oxides*. The cases of combustion we have been considering are examples of rapid oxidation, but oxygen frequently enters into slow combination at ordinary temperatures and without perceptible heat, as in the rusting of iron in the air. Heat, however, always accompanies this slow combustion. An ounce of iron rusted in air, or burnt in oxygen, produces the same amount of heat, but in the former case it requires years for its development, and in the latter only as many minutes. Sometimes, under favorable circumstances, the oxidation becomes so rapid that the accumulated heat produces ignition, causing the phenomenon called *spontaneous combustion*. This is most liable to occur with porous substances which expose a large surface to the air. The tow or cotton used for wiping the lubricating oil

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447. What does Fig. 171 represent? 448. What effects are seen when sulphur and phosphorus are burned in oxygen? To what are they all due? 449. What is oxidation? What are oxides? How does slow differ from rapid combustion? What is spontaneous combustion? Where is it most likely to occur? 450. What

from machinery, and then laid away in heaps, often ignites in this manner, especially if exposed to the sun.

**450. Eremacausis.**—The cause of decay in vegetable and animal substances is the action of oxygen which breaks them up into simpler and more permanent compounds. This slow combustion is called by LIEBIG *eremacausis*. Oxidation is also the grand process by which the earth, air, and sea are purified from contaminations; noxious vapors and pestilential effluvia being destroyed by a process of burning, more slow indeed, but as real as if it took place in a furnace. The offensive impurities which constantly flow into rivers, lakes, and oceans, as well as the decaying remains of the living tribes which inhabit them, are perpetually oxidized by the dissolved gas, and the water thus kept pure and sweet. For this reason waters that have become foul and putrid are purified and sweetened by exposure to the action of air. This effect, however, is largely dependent upon a condition of oxygen which has been but lately discovered (456).

**451. Relation of Oxygen to Life.**—Oxygen is the universal supporter of respiration, and, as this is the most important of the vital processes, it is hence the immediate supporter of life. From this circumstance it was first known as *vital air*. An animal confined in a given bulk of common air, having consumed its oxygen, dies. If immersed in pure oxygen, it lives much longer, but the effect is too powerful—over-action, fever, and in a short time death, are the result. As the introduction of oxygen is the prime physiological event of animal life, the mechanism of all living beings is constructed with reference to this fact. The lungs of the higher races, the spiracula of insects, and the gills of fishes, are all adapted to the same purpose—the absorption of oxygen, either from the air or water. The animal organism is chiefly composed of combustible constituents, and we introduce this wonderful element incessantly, day and night, from birth to death, that it may perform its chemical work. The animal body is an oxidizing apparatus, in which the same changes occur that take place in the flame, only in a lower degree, and a more regulated way. Every

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is the cause of decay? What is it called? What is said of oxygen as a purifier? 451. Why was oxygen called vital air? When an animal is confined in a limited portion of air, what follows? What if in pure oxygen? How are all animals constructed? Of what are they composed? What are they all incessantly doing? For what purpose? What is going on in the animal system? Why is food taken?

organ, muscle, nerve, and membrane is wasted away, burnt to poisonous gases and ashes, and thrown from the system as dead and dangerous matter. If these constant losses are not repaired by the due supply of food, emaciation, decay, and finally death ensue. Starvation is thus unimpeded oxidation—slow burning to death.

**452. Rate of Consumption of Oxygen.**—Of the 15 lbs. of air over every square inch of the earth's surface, one fifth is oxygen. A man consumes by respiration about 2 lbs. each day; that is, he withdraws daily all the oxygen from a column of air two thirds of an inch square, and reaching to the top of the atmosphere, or 45 miles high. In a year he removes all the oxygen over a space of 243 square inches, and in 70 years from an area 118 feet square. Six pounds of pure coal, in burning, consume 16 lbs. of oxygen; a steamship, therefore, which should burn 1,100 tons of coal in crossing the Atlantic, would consume nearly 3,000 tons of oxygen. Assuming the population of the globe 1,000,000,000, and that each individual in respiration requires but 1 lb. per day, assuming as much more for the processes of combustion; and twice as much for the respiration of the animal kingdom, and then doubling this whole quantity for the universal and unceasing functions of decay (probably far too low an estimate), we have an aggregate of over 7,000,000 tons of oxygen withdrawn from the atmosphere *each day*. The oxygen in the atmosphere is computed to be about 1,178,158,000,000,000 tons, which, if separated from the air, and forming a layer of uniform density upon the earth, would be one mile deep.

**453. Oxygen in the World of Waters.**—Enormous as this quantity seems, it is in reality but the bare starting point—the unit of that stupendous scale of prodigality, with which this element has been distributed in nature. Oxygen, condensed into 800 times less space, is the chief constituent of water, forming $\frac{8}{9}$ of its weight. The ocean covers two thirds of the earth, and is estimated as averaging two miles in depth. Could the oxygen imprisoned in this liquid form be set free, it would be sufficient to

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What is starvation? 452. How much oxygen does a man consume in a day? From how much air is the oxygen removed in the same time? In a year? In 70 years? What is the estimate concerning a steamship? What is the whole amount of oxygen in the atmosphere, and how much is consumed each day? 453. What proportion of water is oxygen? If this were set free, what would it form?

form an atmosphere around the globe, nearly a thousand miles deep, and of the same density as that now at the level of the sea!

**454. Proportion in the Solid Earth.**—And these proportions are as nothing compared to the incalculable quantities of oxygen wrought into the solid fabric of the world. Of the three minerals which form the chief mass of the earth's crust, *silica*, *alumina*, and *lime*, the first, and by far the most extensively distributed, contains more than one half its weight of oxygen, and the other two almost one half. It constitutes, also, three fourths of the weight of all animal bodies, and four fifths of that of the vegetable world. Thus, one half the ponderable matter of the earth, so far as man has explored it, is made up of *a single chemical element*, while the crowning wonder is, that when called up before us by the magic of chemistry, it is but an invisible gas,—no man has ever beheld it,—it seems the very type of spiritual existence and invisible power!

**455. Office in Nature.**—The part played by oxygen in the scheme of nature is imposing in the highest degree. In virtue of its boundless abundance, its diffusive nature, the vast range and strength of its attractions, and the unchangeableness of its combinations, it would seem to have been appointed to the grand office of taking charge of all the other elements, and bringing them into an orderly and permanent system. The rocks and waters of the earth consist of materials given over to its custody. Saturated with it they are in a condition of the most perfect chemical stability. Enveloping our planet in its free condition, it manifests an irresistible passion to seize upon and possess all things. The deadly foe of life, it would destroy all organized beings, and pursuing them to the very tomb, decompose and dissolve their structures, carrying back their elements to the quiescent mineral world. This element has, therefore, been personified as the genius of the air—an omnipresent, destructive spirit, which holds the globe in its consuming embrace; which revels in conflagration, and would reduce all things to ashes and rest. But the earth has not been left to the operation of its own forces. Celestial radiations are the antagonists of oxygen, and their agency in saving the world from its desolating influence, will be shown when we consider the subject of Physiological Chemistry (1194).

454. What proportion of the earth's crust is oxygen? Of animal bodies? Of vegetables? What is said to be the crowning wonder of all this? 455. What is

## § II. *Ozone—Allotropic Oxygen.*

**456. How Produced.**—When electric sparks are passed through dry air, a peculiar odor is perceived which has been called the 'electrical smell.' There was much doubt about the cause of it, until the investigations of Prof. SCHÖNBEIN showed that it was an allotropic form of oxygen. From its peculiar odor, its discoverer named it *ozone*. Oxygen may be converted into ozone, not only by electricity, but in various other ways. If a piece of phosphorus be placed in a jar, and partially covered with water, its slow oxidation will soon produce ozone. Or, if we place a little ether in an open vessel, and then introduce into its vapor a moderately heated glass rod, Fig. 174, ozone promptly appears. If it be passed through a red-hot tube, it will be changed into common oxygen, and even a temperature scarcely above that of boiling water robs it of all active power.

FIG. 174.

Making Ozone.

**457. Properties and Test of Ozone.**—Ozone seems to be oxygen greatly intensified in activity. It is armed with a new energy, and is capable of producing changes which, in its ordinary state, are impossible. It corrodes metals upon which before it could not act, for example, silver; it quickly bleaches out colors, which are comparatively permanent in the air; it deodorizes tainted flesh, destroying its effluvium instantly, and carries woody fibre in a short time through a course of decomposition, which, with common oxygen, would require years. This increased activity becomes the test of the allotropic condition. Ozone replaces iodine in its combination with the metals; an effect oxygen cannot produce; hence it decomposes iodide of potassium, setting free the iodine. Free iodine combines with starch, turning it blue; therefore, a test of ozone is made by soaking slips of paper in a mixture of starch and iodide of potassium. The slightest trace of ozone

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said of the office of oxygen in nature? 456. What is ozone? How is it produced? By what is it destroyed? 457. What are the properties of ozone? What is the test of its presence? Give examples? What is its effect when breathed?

turns it immediately blue. Ozonized air irritates the respiratory organs, and a minute fraction of a grain kills a rabbit.

458. If some of the prepared paper be exposed for a few minutes to the open air, it will often turn blue, which is supposed to be owing to the presence of ozone. The amount of ozone in the air is variable, and winds blowing from the sea are said to contain more of it than those which sweep over large tracts of land. Of its mode of production in nature nothing is known: it may be effected by electrical influence. It is probable that it is generated on a large scale in the atmosphere, and that it subserves a high purpose in the economy of the globe as a purifier of the air and hastener of decay.

459. **Theory of Ozone.**—There is much unanimity of opinion as to the explanation of ozone among those who have most ably investigated the subject, and the view has all the more interest as it is part of a general chemical doctrine which has lately become prominent.

460. It is well known that bodies when in *combination* present characters very different from those which they exhibit in the *free state.* It seems, in fact, that few, if any elementary substances are actually known to us in their uncombined condition, and that what we call the 'elements' are, in reality, compounds of at least two atoms of the true element with each other, the atoms being probably in different states. Thus hydrogen gas is not simply H, but $\left.\begin{matrix}H\\H\end{matrix}\right\}$, or $H_2$, or hydride of hydrogen. Chlorine gas is not Cl, but $\left.\begin{matrix}Cl\\Cl\end{matrix}\right\}$, or chloride of chlorine; while cyanogen is not $C_2N$, but $\left.\begin{matrix}C_2N\\C_2N\end{matrix}\right\}$, or cyanide of cyanogen. According to this view the term *atom* applies to that smallest part of an element which can enter into combination, but which is not known in a separate form: while the word *molecule* is used to indicate the smallest quantity of any element which can exist in a separate state. For instance, N is the *atom* of nitrogen, $\left.\begin{matrix}N\\N\end{matrix}\right\}$ its *molecule.*

458. How is it detected in the air? What winds produce the greatest effect? How is it produced in nature? What purpose does it subserve? 459. What is said of the theory of ozone? 460. What is probably the state of the so-called elements? Give examples. What then is meant by *atom*? What by molecule?

**461. Prof. Brodie** maintains that when two particles enter into union with each other, it is because they are in different states—*chemically positive and negative.* Substances cannot combine with each other unless they are in this polar condition, and they retain it in combination. Silver is not oxidized by common oxygen, because they do not become polar by contact. But if silver and oxygen are already combined with other elements, and, therefore, in opposite states, they may be made to unite with each other. Thus, in chloride of silver, the chlorine is chemically negative, and the silver chemically positive; in oxide of potassium, the oxygen is chemically negative, and the potassium chemically positive. If these compounds are brought together, double decomposition results, and oxide of silver is formed thus:

$$\begin{matrix} \overset{-}{\mathrm{Cl}}\ \overset{+}{\mathrm{Ag}} \\ \overset{+}{\mathrm{K}}\ \overset{-}{\mathrm{O}} \end{matrix} = \begin{matrix} \overset{-}{\mathrm{Cl}}\ \overset{+}{\mathrm{K}} \\ \overset{+}{\mathrm{Ag}}\ \overset{-}{\mathrm{O}}. \end{matrix}$$

According to this view, ordinary free oxygen is a medium or neutral body, produced by atoms which are chemically positive and negative; as $\overset{+}{\mathrm{O}}\ \overset{-}{\mathrm{O}} = \mathrm{O_2}$, the molecule of free oxygen; while ozone is polarized or decomposed oxygen.

**462. Schonbein** entertains similar views of the nature of ozone. He says there are two kinds or allotropic modifications of active oxygen, standing to each other in the relation of + to −; that is, there is a positively active and a negatively active oxygen —an ozone and antozone, which, on being brought together, neutralize each other into common or inactive oxygen, according to the equation $+\mathring{\mathrm{O}}-\mathring{\mathrm{O}}=\mathrm{O}$.

## § III. *Hydrogen.*

*Sym. H. Equiv.* 1. *Sp. Gr.* 0.0692.

**463.** Hydrogen was first described as an element by the English chemist Cavendish in 1766. It is never found free in nature, but exists abundantly in combination, forming one ninth by weight of water and a considerable proportion of all organized substances.

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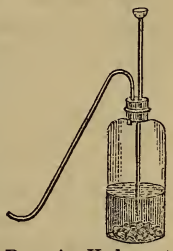
461. What does Prof. Brodie give as the cause of chemical union? Why will not silver unite with common oxygen? How is it in double decomposition? By this view what is ozone? 462. What is Schönbein's view? 463. When and by whom was hydrogen discovered? How is it found in nature? What objection is made to its name? 464. How is it generally obtained? In what ways? Explain Fig. 175. What

The word hydrogen signifies *generator* of *water*, but it is strictly no more applicable to this element than to oxygen.

**464. Preparation.**—Hydrogen is generally obtained by the decomposition of water, which is effected in various ways. A current of electricity passed through water liberates both the oxygen and hydrogen, when they may be collected separately (212). Steam passed through a red-hot gun barrel is decomposed by the iron which combines with the oxygen, setting the hydrogen free. It is commonly prepared, however, by the action of dilute sulphuric acid upon bits of zinc. The zinc is placed in a bottle and covered with water. A cork perforated for the insertion of two tubes is then tightly fitted to the mouth of the bottle, Fig. 175. The tube for admitting the acid dips beneath the water; the other delivers the gas, which is collected in jars in the same manner as oxygen. The water is decomposed by the zinc, which unites with its oxygen, forming oxide of zinc, while the hydrogen is set free and escapes. The sulphuric acid dissolves the oxide of zinc as fast as it is formed, thus maintaining a clean metallic surface continually in contact with the water. The changes are represented by the following equation:

FIG. 175.



Preparing Hydrogen.

$$Zn + HO + SO_3 = ZnO, SO_3 + H.$$

The portions first collected are not to be used, as, when mixed with air, hydrogen gas is always explosive.

**465. Properties.**—As thus prepared, hydrogen has a disagreeable odor arising from the impurities of the materials employed; but pure hydrogen is a colorless, tasteless, inodorous gas, very slightly soluble in water and very inflammable. All attempts to liquefy it, either by pressure or cold, have failed. Dr. FARADAY found that it would escape through the joints of apparatus that were perfectly tight to other gases; its atoms must therefore be comparatively much smaller. A stream of the gas directed against one side of a piece of gold leaf passes through so rapidly that it may be ignited on the other side. It is the lightest of all known substances, being 16 times lighter than oxygen and $14\frac{1}{2}$ times

are the chemical changes? Why are not the first portions used? 465. What are the properties of pure hydrogen? What is said of the smallness of its atoms? Of its

lighter than air. This adapts it for inflating balloons, though coal gas (which contains hydrogen, and is very light) is generally used from its greater cheapness. Owing to its extreme rarity, a bell rung in hydrogen is scarcely audible; and when it is inhaled, the voice becomes remarkably shrill. Though pure hydrogen is not poisonous, it will not support life, and an animal immersed in it soon dies from want of oxygen.

**456. Combustion of Hydrogen.**—There is a strong affinity between oxygen and hydrogen. If these gases are mixed (2H to 1O, by bulk), and then ignited, they combine with a violent explosion. Soap bubbles, if blown with this mixture from a bag, rise, and if fired with a candle, detonate like a pistol. The instantaneous condensation of the gases produces a vacuum, and the sharp report is caused by the collision of the particles of air as they rush in to fill the void.

FIG. 176.

Burning Hydrogen.

**467.** Burning bodies are commonly extinguished when plunged into hydrogen, although a jet of oxygen will burn in it. Oxygen and hydrogen burn quietly when brought cautiously into contact, emitting a feeble blue light. Three properties of hydrogen may be shown by a very simple experiment—its levity, combustibility, and explosiveness. A jar is filled with it, and though held mouth downward, it does not escape. If a lighted candle be introduced, Fig. 176, it is extinguished, while the gases burn at the mouth of the jar. If the candle is withdrawn, it is relit by the flame at the mouth, while, if the jar is reversed, the hydrogen is mixed with a little air, and produces a slight explosion.

FIG. 177.

Philosophical Candle.

**468.** If hydrogen is generated in a jar and allowed to escape through a fine tube, Fig. 177, into the air, it burns, when ignited, with a small, steady flame, giving out but little light, though producing intense heat. In all cases where hydrogen is burned with oxygen, water is the product. If a cold, dry glass is held over the jet, it is quickly covered with a film of dew, which rapidly increases to drops of water. The gases unite to form steam, which then condenses into the liquid state.

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use in balloons? How is it related to sound? To life? 466. How is its affinity for oxygen shown? What causes the explosion? 467. What is taught by the experiment, Fig. 176? 468. What is the product when hydrogen is burned? How is

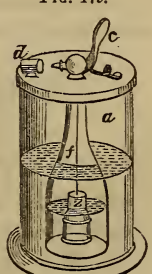
**469. Singing Flames.**—A common experiment is to lower a glass tube over the gas jet, as represented in Fig. 178, when a clear musical tone is produced. This is explained by supposing that the rapid current of air which rises through the tube interrupts the combustion, and, mingling with the hydrogen, produces a series of slight explosions in such rapid succession as to cause a continuous sound. The pitch of the sound varies with the size and length of the tube, and with the size of the jet; and a series of tubes and jets may therefore be so graduated as to give the notes of the musical scale. A very pretty effect is produced by introducing the flame a short way into the tube, which may be held steadily in position by a clamp. No sound is emitted; if now the experimenter pitches his voice to the proper note, the flame begins to sing in unison. A person twenty or thirty feet away, by thus speaking to it, causes the jet to start into song—a remarkable illustration of the effect of transmitted pulsations.

Fig. 178.

Singing Hydrogen Flame.

**470. Combustion of Hydrogen by Condensation.**—If a small quantity of the solution of the metal platinum be evaporated on a piece of writing paper, and the paper burned, the metal remains in a state of fine division known as *spongy platinum*. If now a stream of hydrogen be directed upon a little ball of platinum sponge, it instantly becomes red hot, and remains so as long as the current lasts. The metal contains atmospheric oxygen condensed within its pores, and by condensing the hydrogen also, their particles are brought within the range of affinity, and combination takes place with the production of heat. Dobereiner's lamp is a contrivance for employing this principle. The outer glass vessel, *a*, Fig. 179, contains dilute sulphuric acid. The inner glass vessel, *f*, is without a bottom, and has suspended within it a piece of zinc. When the acid comes in contact with the zinc, hydrogen is immediately generated, and fills the vessel, *f*, pushing down the sulphuric acid so that it is no

Fig. 179.




Dobereiner's Lamp.

this shown? 469. How are musical tones produced? What is the explanation? How is the effect of transmitted pulsations illustrated? 470. How may combus-

longer in contact with the zinc, and the production of gas of course stops. On touching the lever, *c*, a valve is opened, and the jet of gas, as it escapes, strikes upon the platinum at *d*, which is made red hot. As the gas leaves the vessel, *f*, the acid again rises into contact with the zinc, more hydrogen is set free, and thus the effect is constant.

**471.** But the porous condition of the metal is not essential to this action. Clean slips of platinum or other metals will condense the gases upon their surface sufficiently to cause rapid combination. Other bodies also beside hydrogen, as vapors of alcohol and ether, may be oxidized by this peculiar surface action. Hydrogen is remarkable among the elements for the enormous amount of chemical energy manifested by a small quantity of matter. Thus in combination it perfectly neutralizes 36 times its weight of the intense element chlorine, and extinguishes the properties of 125 times its weight of iodine.

**472. Is Hydrogen a Metal?**—Hydrogen in combination is replaced by metals, and has many analogies with them (707); hence Dumas and others have supposed that if, like mercurial vapor, it could be condensed into a liquid, it would be found to possess a metallic nature. But it has been found that hydrogen is also replaced by the strongest anti-metal chlorine, and that its analogies with the chlorous elements are as numerous, as strongly marked, and as important as with those of the basylous class. We must hence regard it as a neutral or intermediate body.

## § IV. *Compounds of Oxygen and Hydrogen.*

### WATER.

(*Protoxide of Hydrogen.*) *Sym.* HO. *Equiv.* 9. *Sp. Gr.* 1.000.

**473.** Of the importance of water in the economy of nature little need be said; it is obvious to all. It is the most abundant substance that we know, and it seems as if the whole scheme of nature were conformed to its properties. Turning to solid ice, or exhaling into invisible vapor, its changes of form involve the very history of the globe (1271). Rising from the ocean, condensed upon the land, and flowing back again to the sea, it carries on in

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tion be effected by condensation? Explain the action of Doebereiner's lamp. 471. What illustrations are given of surface condensation? For what is hy-

its circulation the grand processes of the world. Composing four fifths the weight of the vegetable kingdom and three fourths that of the animal, it is the first condition of all organization, and by innumerable transformations and decompositions, it is essential to the continuance of organic life.

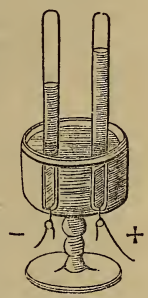
**474.** Nor is it less indispensable in the laboratory of the chemist. It is the ready, invaluable medium of a thousand operations; it is involved in nearly every chemical process; in fact, the chemistry of water, theoretical and practical, might fitly be taken to represent the present state of the science.

FIG. 180.

Decomposing Water.

**475. Composition.**—Water is a compound of 8 parts by weight of oxygen to 1 of hydrygen, or by bulk 1 of oxygen to 2 of hydrogen. Its composition may be proved in many ways, but one of the most simple is to throw a little metallic potassium upon its surface. The metal instantly decomposes it, seizing upon the oxygen with such violence as to produce vivid combustion, Fig. 180; the water seems set on fire.

FIG. 181.




Electro-Decomposition.

**476.** But the composition of water may be shown in the most perfect manner by sending an electric current through a vessel of it, Fig. 181, as already described (212). The gases are set free in the exact proportions given above, and if mixed together and ignited, they combine with a loud and sharp explosion, the product being pure water. The composition of water is thus demonstrated by both analysis and synthesis. An arrangement for exploding gases to determine the amount of their condensation is called a *Eudiometer.*

**477.** Water is not only decomposed as stated above, but also by sodium, iron, zinc, and many other metals; in fact, they are classified according to their degrees of power in this respect. In numberless operations of chemistry, the elements of water are separated and reunited, and the same thing is going on perpetually in vegetable and animal organisms.

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drogen remarkable? 472. How must we regard it as a neutral body? 473. How are the properties of water related to the scheme of nature? 474. How does the chemist regard it? 475. What is its composition? What simple experiment proves it? 476. What does Fig. 181 represent? What is an Eudiometer? 477. How

**478. General Properties.**—Water, as is well known, is a transparent, tasteless, inodorous liquid. It is but very slightly condensible; according to REGNAULT, being compressed 1-47 millionth of its bulk for each atmosphere of pressure (563), and is perfectly elastic, as it regains its full dimensions when the pressure is removed. It evaporates at all temperatures; boils at 212°, and freezes at 32°. At 60°, a cubic inch of pure water weighs 252.456 grains, which is 815 times the weight of an equal bulk of air. An imperial gallon weighs 70,000 grains, or just 10 lbs. The American standard gallon weighs 58,972 grains of pure distilled water at the maximum density (484). In thin sheets, water is colorless, but when viewed in thick masses, it has a decided tint. Light passed through fifteen feet of pure distilled water, emerges of a bright and delicate blue-green, and by augmenting the thickness, the color is deepened. Natural waters are discolored by various impurities in different places.

**479. Water Purified by Freezing.**—During freezing, the substances dissolved in water are expelled; hence the ice of sea water (as is well known to sailors), when melted, becomes fresh water. For the same reason, water from melted ice contains no air, nor gas—fish cannot live in it. Ice melted under spirits of turpentine, where no air can get access to it, produces water so cohesive, that it can be heated far beyond its boiling point, when it bursts into explosive ebullition (288).

FIG. 182.

Forms of Ice Flowers. (TYNDALL.)

**480. Liquid Flowers in Ice.**—When a ray from the sun or an electric lamp is made to pass through a block of pure ice, a portion of the heat is arrested, and must, of course, produce change. As it cannot warm the ice, it melts it. But the ice particles return to the liquid state in definite order, and, upon examining it with a magnifier, the ice is seen to be filled with beautiful flower-like figures, such as are shown in

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are metals classified? What is everywhere occurring? 478. What are the general

Fig. 182. These consist of water, but as the liquid formed cannot quite fill the space of the melted ice (484), there occurs a little vacuum, which looks like a globule of burnished silver in the centre of the flower.*

**481. Snow Crystals.**—The aqueous vapor of the atmosphere, condensed by cold in winter, or at great heights in summer, assumes the most beautiful crystalline forms—those of snow flakes. Perfect snow flakes are six-sided stars, which shoot out an infinity of delicate needles, all diverging from each other at an angle of 60°. These frozen blossoms, as they have been aptly termed, are seen in an endless variety of most exquisite forms, a few of which are shown in Fig. 183.

**482.** The great specific heat of water (274) is a powerful agency in controlling climate. It is four times greater than that of air; that is, a pound of water in cooling one degree, would warm four pounds of air one degree. But as water is 770 times heavier than air, it is obvious that a cubic foot of water in cooling one degree, would warm four times 770 cubic feet of air, or 3,080 cubic feet one degree. Hence, the vast amount of heat stored up in oceans and lakes, being gradually imparted to the air during winter, modifies the severity of the cold, and explains the fact that island winters are less severe than those of continents or inland places.

**483.** The very stability of nature seems to depend upon this quality of the earth's aqueous element. If the watery masses of

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* Prof. TYNDALL, who has advanced these beautiful researches, thus eloquently discourses on this property of ice: 'To many persons here present, this block of ice may seem of no more interest and beauty than a block of glass; but, in the estimation of science, it bears the same relation to glass that an oratorio of Handel does to the cries of a market place. The ice is music, the glass is noise; the ice is order, the glass is confusion. In the glass, molecular forces constitute an inextricably entangled skein; in the ice they are woven to a symmetric web, the miraculous textures of which I will now try to reveal.—How shall I dissect this ice? In the solar beam,—or, failing that, in the beam of an electric lamp, we have an anatomist competent to perform this work. It shall pull the crystal edifice to pieces, by accurately reversing the order of its architecture. Silently and symmetrically the crystallizing force builds up the atoms, silently and symmetrically the electric beam will take them down! Probably few here present were aware of the beauty latent in a block of common ice. And only think of lavish nature operating thus throughout the world! Every atom of solid ice which sheets the frozen lakes of the North has been fixed according to this law. Nature 'lays her beam in music,' and it is the function of science to purify our organs, so as to enable us to hear the strain.' (TYNDALL'S Lectures on Heat.)

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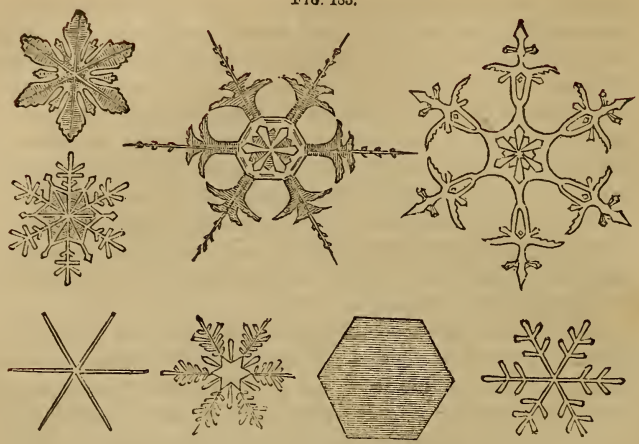
properties of water? 479. What is the effect of freezing upon water? What is said of water from melted ice? 480. How are liquid flowers produced in ice? 481. What are snow flakes? Describe them. 482. How does the great specific heat

FIG. 183.



Forms of Snow Flakes. (GLAISHER.)

the globe, and that large proportion of it contained in our own bodies, lost and acquired heat as promptly as mercury, the variations in temperature would be inconceivably more rapid than now; the inconstant seas would freeze and thaw with the greatest facility, while the slightest changes of weather would send their fatal undulations through all living systems. But now the large amount of heat accumulated in bodies of water during summer, is given out at a slow and measured rate; the climate is tempered, and the transitions from heat to cold are gradual and moderated.

484. **Unequal Expansion of Water.**—This liquid contracts as its temperature falls from the boiling point till it reaches 39°, when it remains stationary for a time. It then begins to expand, and in cooling through 7 degrees to the freezing point, it reaches the same volume it had at 48°. The point of greatest contraction is called the *maximum density* of water. This fact is of great importance in nature. If water continued to contract as it cooled, it would be denser and heavier at the freezing point, and, consequently, sink. Lakes and rivers would then begin to freeze at the

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of water affect climate? 483. What is said of the importance of this quality in nature? 484. What is said of the unequal expansion of water? If water contin-

bottom first, and, in the course of the winter, would become solid masses of ice; while the length of time required to thaw them would greatly prolong the cold season. But as the surface stratum of water approaches the freezing point and freezes, it expands, and, becoming lighter, floats, and thus the coldest water and ice are kept at the surface, where, as they are almost perfect non-conductors of heat, they protect the mass of water below from the cold above. In freezing, water expands with such power as to burst the strongest vessels. Percolating through the minute crevices and fissures of rocks in summer, it freezes in winter, and expands with a force which breaks the solid stones, crumbling them into soil fit for the support of vegetable life.

485. The property of water by which these effects are produced, has been regarded as exceptional, but this is not the case. Bismuth and other metals in the act of solidifying also expand. Nor is this effect, probably, any real exception to the law of expansion by heat. Another force is evidently brought into play which *masks* the regular action of the heat. Clay contracts by heat, but it is due to the shrinkage from loss of water, which happens to be greater than the expansion produced by heat. So there can be little question that the play of crystalline forces interferes with the result. As liquids crystallize, on approaching solidification, there is a rearrangement of the molecules with enlarged interspaces and consequent expansion.

486. **Atomic Constitution of Water.**—There are various reasons for supposing that the composition of water, instead of being HO, is $H_2O_2$. *First*, the heat-absorbing power of aqueous vapor is high, like that of the complex-atomed gases (346). *Second*, when H and O combine to form water, there is so great a loss of mobility as to suggest that the atoms, instead of uniting in simple pairs, combine into higher and more sluggishly moving groups. *Third*, the excessive amount of heat that results from their combination, suggests a great amount of atomic motion; and, *fourthly*, this idea is countenanced by the behavior of water in expanding by cold, as it approaches the freezing point, as just noticed.

487. **Water of Combination.**—Water unites with bodies with three degrees of intensity. In its closest union it forms com-

ned to contract as it cooled, what would follow? What instances are given of the force with which water expands in freezing? 485. Is this property of water exceptional? What is the probable explanation? 486. What reasons are given for sup-

pounds known as *hydrates*, where the water is so intimately combined that a heat approaching to redness is required to separate it; slaked lime is such a hydrate. Secondly, it combines with crystalline bodies in definite proportions. This is termed the *water of crystallization*, to distinguish it from the *water of hydration*. The formula for crystallized sulphate of magnesia, for example, represents both states of combined water:

$$MgO, SO_3, HO + 6\ Aq.$$

Thirdly, water combines in all proportions, in a still more loose, chemico-mechanical way, as a solvent.

488. Water is perfectly neutral, manifesting neither acid nor basic properties, and yet it is capable of playing the part of both. It combines powerfully with acids, and, acting the part of a base, is known as *basic* water. Hydrated sulphuric acid, $HO, SO_3$, is thus a sulphate of water, nor can the water be expelled from the combination, except by a more powerful base. It combines also with bases, potash for example, playing the part of an acid, and can only be displaced by a stronger acid.

489. **Solvent Power of Water.**—Its perfect neutrality enables it to take on the properties of other substances, and hence with equal facility it becomes sweet, sour, salt, astringent, bitter, or poisonous, according as the bodies it dissolves possess these properties. This solvent power is variable upon different substances, and at different temperatures. Thus, a pound of cold water will dissolve two pounds of sugar, while it will only take up two ounces of common salt, two and a half of alum, and eight grains of lime. Heat generally increases the solvent power of water; thus boiling water will dissolve 17 times as much saltpetre as ice water. But there are exceptions to this rule; ice water dissolves twice as much lime as boiling water.

490. **The Water Atmosphere.**—Water dissolves gases in the most diverse proportion, taking up 700 times its bulk of ammonia; its own bulk of carbonic acid; $\frac{1}{25}$ its bulk of oxygen, and still less of nitrogen. There is, therefore, an atmosphere diffused throughout all natural waters, which is richer in oxygen than common

posing that the atomic constitution of water is $H_2O_2$? 487. What are hydrates? What is meant by water of crystallization? How else does water combine with bodies? 488. What is basic water? Examples. When does it play the part of an acid? 489. How does the solvent power of water vary? What is the effect of heat

air, and hence better adapted for supporting the life of aquatic animals. The gases absorbed by water give it a brisk, agreeable flavor, and if driven off by boiling, the liquid becomes insipid.

**491. Different Kinds of Water.**—As water dissolves a little of nearly every substance with which it comes in contact, it is never found perfectly pure in nature. Hence there are many varieties of natural water, as spring, river, rain, sea, and mineral water. Rain falling in the country, away from habitations, and after a protracted wet season, is the purest water nature produces, as it is contaminated only with the natural gases of the atmosphere. In cities, as it falls through the air, it absorbs the various organic and gaseous impurities with which it comes in contact, and, flowing over the roofs of houses, carries down the deposited soot, dust, &c. Water from melted snow is purer than rain water, as it descends through the air in a solid form, incapable of absorbing gases.

**492. Mineral Impurities.**—Rain water, which has filtered through the porous soil and strata of the earth, dissolves such portion of its soluble materials as it meets with, and carries them down to the lower levels, so that they may ultimately collect in the sea. The amount of mineral water thus dissolved is remarkably various. The water of the River Loka in Sweden, which flows over insoluble granite, contains only $\frac{1}{20}$ of a grain of mineral matter in an imperial gallon. Common well-waters and spring and mineral waters contain from 5 to 60 grains per gallon. Sea water contains 2,600 grains to the gallon; and that from some parts of the Dead Sea or the Great Salt Lake of Utah, as much as 20,000 grs. to the gallon—400,000 times as much as the Loka water.

**493.** The mineral impurities of well and spring water are chiefly lime, magnesia, soda, and oxide of iron, combined with carbonic and sulphuric acids, which form carbonates, sulphates, and common salt. The most universal ingredients, however, are carbonate and sulphate of lime. Carbonate of lime, or limestone,

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upon it? 490. How much ammonia does water dissolve? How is it with other gases? What is the effect of the dissolved gases upon the water? 491. Why are there so many varieties of natural water? How do different localities cause waters to differ? What are the purest waters? 492. How does water obtain its mineral impurities? Give instances of their variable quantity. 493. What are the chief

is not soluble in pure water, but dissolves in water containing free carbonic acid, which is present in most natural waters.

494. **Sea Water.**—The solid constituents of sea water amount to about 3½ per cent. of its weight, or nearly half an ounce to the pound. Its saltness is a necessary result of the circulation of matter. Rivers flow into the ocean with their saline constituents, while the water which evaporates from the sea is nearly pure. The ocean, therefore, is the great depository of everything that water can dissolve and carry down from the surface of the continents, and, as there is no channel for their escape, they constantly accumulate. The continuance of this process for numberless ages accounts for the present saline condition of the oceans. In the same way all lakes into which rivers flow, and which have no outlet, are salt lakes. The Dead Sea, for example, is situated at the bottom of an immense basin—several hundred feet lower than the Mediterranean, and has no outlet. The Jordan flows into it, bearing 75 grains of saline matter to the gallon, and there is no escape but by evaporation; hence its excessive saltness.

495. **Mineral Waters** are usually those of springs which contain a considerable amount of various saline matters. Those abounding in salts of iron are called *chalybeate*, or *ferruginous* waters. If the waters are brisk and sparkling, carbonic acid gas is present, and they are termed *carbonated*, or *acidulous* waters. If the active ingredient be sulphur, the spring is called *sulphurous*. The water of the celebrated Congress Spring, at Saratoga, contains the following ingredients in a gallon:

| | |
|---|---|
| Chloride of Sodium, | 399,246 grains. |
| Iodide of Sodium, and Bromide of Potassium, | 6,000 " |
| Carbonate of Soda, | 9,213 " |
| Carbonate of Magnesia, | 100,941 " |
| Carbonate of Lime, | 103,416 " |
| Carbonate of Iron, | 1,000 " |
| Silex and Alumina, | 1,036 " |
| Total solid contents, | 611,852 grains. |

496. **Hard Water.**—Water derives its quality of *hardness* from the presence of salts of lime, chiefly the sulphates; a single grain of which will convert 2,000 grains of soft into hard water. When

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mineral ingredients of well and spring water? To what does carbonate of lime owe its solubility? 494. Explain the cause of the saline condition of the ocean.

common soap is put into hard water, instead of dissolving in it, as it does in soft water, it curdles, or is decomposed, and a new soap is formed which contains lime instead of potash or soda. This new soap will not dissolve, and may often be seen on the surface in the form of a greasy scum. It adheres to whatever is washed in it, and gives to the touch the unpleasant sensation of hardness. To test this quality of water, dissolve a little soap in alcohol, and place a few drops of it in the water to be examined. If it remains clear, the water is perfectly soft; if it becomes turbid or opaque, the water is ranked as hard. Hard water is a less perfect solvent than soft water, and is, therefore, inferior to it for culinary purposes.

**497. Organic Impurities of Water.**—From the dust and insects of the air, drainage of residences, the decay of leaves and animals, and a multitude of other causes, water is liable to organic contaminations. These may be either mechanically suspended, or dissolved in it. Water containing dissolved organic matter is highly dangerous to health, and should be carefully avoided. Solution of permanganate of potash is decomposed and decolorized by it, and, therefore, water which discharges the color from much of this reagent should be viewed with suspicion.

**498.** Organic impurities, if suspended mechanically in water, are noxious, but they are generally attended by a correction more or less efficient in the shape of animalculæ, which feed upon them. These living inhabitants are never found in freshly fallen rain water, caught at a distance from houses, nor in spring or well water; but they more or less abound in cistern and reservoir, marsh, pond, and river waters. The River Thames has been found to contain 23 different species of these organisms. They make a frightful appearance when exhibited by the oxy-hydrogen microscope, but they perform an invaluable service in consuming dead organic matter, and reducing it to its ultimate and innocent constituents—carbonic acid, water and ammonia.

**499. Purification of Water.**—The best method of purifying water is by distillation; to render it perfectly pure, it must be redistilled at a low temperature, in silver vessels. By filtration through sand, crushed charcoal, or other closely porous media,

How is it with the Dead Sea? 495. How are mineral waters classed? 496. What is hard water? Its action on soap? Its test? 497. Whence come its organic impurities? Why should such water be avoided? How may we test it?

water may be deprived of suspended impurities, and of all living beings. Boiling kills all animals and vegetables, expels gases, and precipitates carbonate of lime, which constitutes the *fur* or crust often seen lining tea kettles and boilers. Alum (two or three grains to the quart) cleanses muddy or turbid water. It is decomposed by carbonate of lime, and the alumina set free carries down the impurities mechanically; but the sulphuric acid of the alum, combining with the lime, forms sulphate of lime, and makes the water harder than before. The alkalies, potash or soda, soften water by decomposing and precipitating the earthy salts.

500. **Peroxide of Hydrogen,** $HO_2$, has been produced by the chemist, and called *oxidated water.* It is a transparent, sirupy liquid, with an astringent taste, a decided odor, and possesses active bleaching properties. It is very unstable in composition; the mere contact of various substances causing it to decompose explosively.

## § V. *Nitrogen and its Compounds.*

### NITROGEN.

*Sym. N. Equiv.* 14. *Sp. gr.* 0.971.

501. This gas was discovered by Rutherford in 1772. It is very extensively diffused in nature, forming about four fifths of the atmosphere, in which it plays the important part of diluting the oxygen, and adapting it to the conditions of life. It is an important element of the vegetable kingdom, entering in considerable quantity into many of its compounds. It is supplied to plants by ammonia and nitric acid, and exerts a very favorable influence upon the growth of vegetation. Our food is largely composed of nitrogen, and it forms 16 per cent. of the tissues of the animal body. It is an essential part of many powerful medicines, as quinine and morphia, and of some of the most dangerous poisons, as strychnine and prussic acid. Nitrogen is not found in any of the mineral formations of the earth's crust, except in some varieties of coal.

502. **Preparation.**—It is called nitrogen, *generator of nitre,*

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498. What is said of animalcula in water? 499. Mention the various modes of cleansing water? 500. What are the composition and properties of peroxide of hydrogen? 501. What are the proportion and office of nitrogen in the atmo-

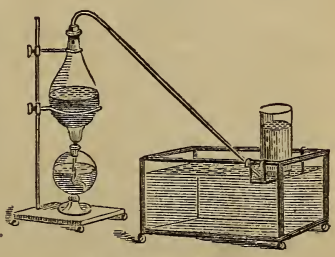
because it exists in that substance, and may be produced from it. It is most commonly prepared by withdrawing oxygen from a portion of air. A small bit of phosphorus is placed in a little cup and floated on the water in a pneumatic trough. It is then set on fire and a jar placed over it, as in Fig. 184. The phosphorus takes the oxygen, forming phosphoric acid, which fills the jar with a white vapor; but this is soon absorbed by the water, and nitrogen alone is left, the water rising to occupy the space of the vanished oxygen. One hundred volumes of water dissolve about two and a half volumes of nitrogen.

Fig. 184.

Preparing Nitrogen.

**503. Properties.**—Nitrogen is a transparent gas without taste or color, and has never been condensed into a liquid. It is remarkable for chemical inertness, and can only be combined with other substances by indirect means. Owing to its weak affinity for the other elements, it forms very unstable compounds, and on the slightest occasion escapes from them in its gaseous form. It supports neither combustion nor respiration: a lighted taper introduced into it is immediately quenched, and animals placed in it quickly die, not from its poisonous action, but from lack of oxygen. Hence it was formerly called *azote*, or life destroyer.

Fig. 185.



Making Nitrous Oxide.

**504. Nitrous Oxide, NO.**—Oxygen combines with nitrogen to form a series of five compounds, remarkable as illustrating in a perfect manner the law of multiple combination. (See Chart.) The first in the series is protoxide of nitrogen, or nitrous oxide, called also, from its peculiar effects when respired, laughing gas, or exhilarating gas. It is prepared from nitrate of ammonia by moderately heating this salt in a flask. The gas escapes through a tube, and is collected in jars over water, Fig. 185. Four ounces of the salt produce one cubic

sphere? How is it supplied to plants? Where else is it found? 502. Why is it called nitrogen? How is it prepared? 503. What are its properties? Why are its compounds unstable? Why was it called *azote*? 504. For what is the nitrogen

foot of the gas. It should be allowed to stand for some time over water, to absorb any nitrous acid that may chance to be formed. The chemical change may be thus represented:

$$H_4NHO, NO_5 = 4HO + 2NO.$$

One atom of nitrate of ammonia (or nitrate of oxide of ammonium), yields four atoms of water and two of protoxide of nitrogen.

**505. Properties.**—Nitrous oxide is a neutral, colorless, transparent gas, of a slightly sweetish taste, and very soluble in water —cold water absorbing about three fourths of its volume. Sp. gr. 1.527. It is an active supporter of combustion, relighting a glowing candle when plunged into it, and intensifying the combustion of phosphorus almost equally with pure oxygen. A pressure of 50 atmospheres at 45° condenses it into a clear liquid which boils at about 1126°, and may be frozen at about—150°.

**506.** When breathed this gas produces a transient intoxication, attended sometimes with an irresistible propensity to laughter, and at others with a tendency to muscular exertion, individuals being variously affected according to temperament. The gas should be pure, and even then the experiment is not a safe one where there is an over-active circulation in the brain. These effects may undoubtedly be ascribed to an augmented oxidation, produced in the system by the gas. When taken into the lungs, being far more soluble than oxygen, it is rapidly dissolved in the blood, and quickly diffused throughout the body.

**507. Nitric Oxide** $NO_2$, (*Deutoxide of Nitrogen*), is formed by the action of nitric acid upon slips of copper in a similar way to the production of hydrogen, Fig. 175. A portion of the nitric acid is decomposed, giving up three atoms of its oxygen to the copper, $NO_2$ escaping. The oxide of copper thus produced unites with a portion of the nitric acid, forming nitrate of copper which gives a blue color to the solution.

$$3Cu + 4NO_5 = 3CuO, NO_5 + NO_2.$$

Nitric oxide is a colorless, irrespirable gas that has not been liquefied, and which extinguishes most burning bodies. Brought in contact with air, it acquires oxygen and produces red fumes of $NO_4$.

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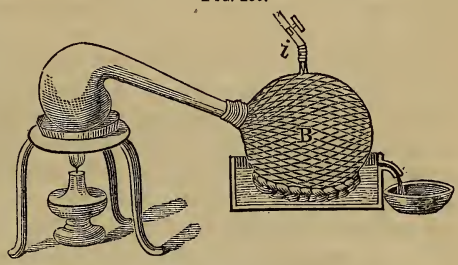
and oxygen group of compounds remarkable? How is nitrous oxide prepared? Explain the chemical changes. 505. State its properties. 506. What are its effects when breathed? How is this action accounted for? 507. What is the composition of nitric oxide? How is it produced? Give the equation. What are its

**508. Nitrous Acid,** $NO_3$, *formerly Hyponitrous Acid.*—This is a thin mobile liquid, producing an orange-red vapor, and forming a class of salts known as the *nitrites*. *Hyponitric Acid* (*Peroxide of Nitrogen*), $NO_4$, is an orange-colored fluid with a cherry-red vapor. It boils at 82°, and solidifies at 8°.

**509. Nitric Acid (Aqua Fortis),** $NO_5$, is a colorless liquid (sp. gr. 1.521) with an intensely sour taste. It smokes when exposed to the air, and is partially decomposed by the action of light, hyponitric acid being formed, which gives it a yellow color. It unites with bases forming an extensive series of salts—the *nitrates* — which are all soluble in water; hence, nitric acid cannot be precipitated. It is obtained by decomposition of its salts. Equal weights of nitrate of potash and sulphuric acid are placed in a glass retort, which is supplied with a receiver B, kept cool by cold water flowing over it from the tube *i*, by means of a netting, Fig. 186. With the application of heat, the nitrate is decomposed, and the acid distils over into the receiver. The change is thus shown:

Fig. 186.




Preparing Nitric Acid.

$$(KO, NO_5) + 2(HO, SO_3) = (KO, HO, 2SO_3) + (HO, NO_5).$$

That is, one atom of nitrate of potash and two of sulphuric acid furnish one atom of bi-sulphate of potash and one of hydrated nitric acid.

**510.** Nitric acid stains the skin, nails, and many other animal substances of a yellow color, and is therefore used to produce yellow patterns upon woollen fabrics. It is also employed for etching on copper, for assaying or testing metals, and as a solvent for tin by dyers and calico printers. In consequence of its large proportion of oxygen, it corrodes the metals with great energy, and

properties? 508. What is nitrous acid? Hyponitric acid? 509. What are the properties and composition of nitric acid? Why can it not be precipitated? How is it obtained? Explain the reaction. 510. For what is it used? What of its

hence is the most powerful of oxidizing agents. It ignites powdered charcoal and oil of turpentine, and oxidizes phosphorus so rapidly as to produce an explosion.

**511.** This acid is found in nature in combination with potash, soda, or lime in the soil of various localities; with potash it constitutes the saltpetre of commerce. It occurs also in small quantity in rain water, especially after thunder storms, and is supposed by some to be produced by lightning, which combines the gaseous nitrogen and oxygen. Others suppose it to be produced by the oxidation of ammonia which always exists in the air.

**512. Ammonia**, $H_3N$ (*Ammonium*, $H_4N$*). This is the only known compound of nitrogen and hydrogen. They do not combine when mixed or heated, but only in the nascent state. Ammonia is therefore a constant product of the decomposition of organic substances which contain nitrogen. It is produced from the destructive distillation of horns and hoofs, which are rich in nitrogen, but the chief source of commercial ammonia is the liquor of the gas works. The gas is conveniently obtained by heating equal parts of newly slaked lime and dry powdered sal ammoniac in a glass. The lime takes the chlorohydric acid, forming chloride of calcium, while gaseous ammonia is set free. The change may be thus shown:

FIG. 187.

Producing Ammonia.

$$H_3N, HCl + CaO = CaCl, HO + H_3N.$$

The gas may be collected in jars in the pneumatic trough, but it must be over *mercury*, as water absorbs it. It is, however, more convenient to procure it by what is called the method of *displacement*. The gas generated in the lower vessel, Fig. 187, being lighter than the air, accumulates in the upper portion of the inverted jar, displacing the air and expelling it downward.

**513. Properties.**—Ammonia is a colorless, irrespirable gas of a pungent, caustic taste, lighter than air (sp. gr. 0.59), and possesses strong alkaline properties, changing vegetable blues to green and yellows to brown. It neutralizes acids and forms definite salts.

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oxidizing power? 511. How is it found in nature? 512. What is the composition of ammonia? When only is it formed? What is its chief source? How may it be obtained? How best collected? 513. What are the properties of ammonia?

* See page 288.

Being a gas, it is called *volatile* alkali, to distinguish it from those which are fixed or solid. From the circumstance that it was derived from the horns of harts, it was called *spirits of harts-horn.* Ammonia is recognized by its odor. If a rod dipped in chlorohydric acid be brought near a source of ammonia, a white cloud is produced by the union of the two in visible gases, Fig. 188.

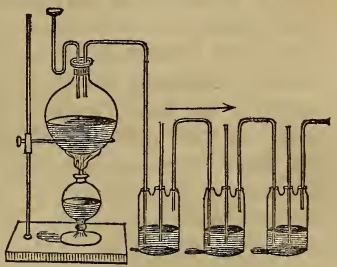
**514.** Ammonia is used medicinally in various ways. It is administered internally as a stimulant, and applied externally as a counter irritant. Mixed with olive oil, it forms *volatile liniment.* It is the best antidote to prussic acid, but in large doses it is poisonous. It is of many uses to the chemist.

Fig. 188.

Testing Ammonia.

**515. Solution of Ammonia.**—Ammonia is rapidly absorbed by water which will take up 700 times its volume of it, forming the *aqua-ammonia* of commerce. This is best prepared by evolving the gas from slaked lime and sal ammoniac, and passing it through a series of bottles. In making solutions of the absorbable gases several difficulties have to be guarded against. The action in the evolution flask is liable to various interruptions, while the water present in the apparatus rapidly absorbs the gas. This creates a partial vacuum, and the consequence is, that the water in the jar flows back into the flask, thus putting an end to the process; also, if the gas is generated faster than it is absorbed, there arises the danger of an explosion, unless there is a free outlet to the apparatus. These dangers are obviated by the arrangement known as Woulfe's Bottles, Fig. 189.

Fig. 189.



Woulfe's Bottles.

**516.** The flask in which the gas is generated is provided with a safety tube which serves both as a means of introducing a liquid and as a protection against the above mentioned accidents. When the liquid is poured in, a

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514. What are some of its uses? 515. Explain the process for forming aqua-ammonia? What trouble is to be guarded against? 516. By what means? 517. What

portion of it is retained in the bend of the tube, acting there as a valve to prevent the access of air to the flask. Each bottle has an upright tube in the middle neck which acts as a safety tube, allowing the air in case of a vacuum to pass in, or the liquid to flow out, if the pressure of the gas becomes too great. The other tubes serve to connect the bottles with the flask and with each other.

**517.** Cold saturated aqua ammonia is lighter than water, boils at 130°, and freezes at—40°. It is a colorless liquid with a pungent odor and strong alkaline taste. It is much used by chemists, and affords the best means of procuring ammonia, as the gas is readily expelled by heat.

## § VI. *Carbon.*

*Sym.* C. *Equiv.* 6. *Sp. Gr.* (*Diamond*), 3.52. (*Vapor*), 0.829.

**518.** Carbon, from the Latin *carbo*, coal, is the name applied to the solid element of organic bodies with which we are familiar in the various forms of charcoal, mineral coal, lampblack, &c. It is on every account a most interesting element, and plays a very important part in the operations of nature. Carbon has three well marked allotropic forms—the diamond, graphite, and charcoal.

**519. Properties of the Diamond.**—The purest form of carbon is the *diamond*—a very extraordinary kind of matter. It is a crystal the most brilliant and precious of gems, and the hardest body known. Diamonds are found in the earth in various places, usually in the form of rounded pebbles covered with a brownish crust. Of their mode of production nothing whatever is known. The finest specimens are perfectly colorless and limpid, but they are also of various colors. The diamond has a very high refractive and dispersive power by which it flashes the most varied and vivid colors of light. It is a non-conductor of electricity, and resists the action of all known chemical substances.

**520. Combustibility.**—The diamond remains unchanged at a very high degree of heat; but if made red-hot and carried into pure oxygen, it burns with a steady glow, like a little star, the

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are the properties of aqua ammonia? 518. What is carbon? What are its three allotropic forms? 519. What is the diamond? How is it formed? Its properties?

product being carbonic acid. From its high refractive power, resembling in this respect organic substances (315), NEWTON predicted that it would prove not only combustible, but of *organic origin*. This view seems to be supported by the fact that the crystal on being burned leaves a trace of ash in the form of a cellular net work. In the flame of the voltaic arc, the diamond becomes white-hot, swells up, and is converted into a black coke-like mass.

**521. Uses.**—Being a powerful refractor of light, the diamond has been sometimes employed for the lenses of microscopes, but it is chiefly used for cutting glass and drilling apertures through other gems. Diamond crystals are in the form of a regular octohedron, but their faces are often a little convex, as shown in the Fig. 190. Only the natural faces of the crystal can be used for cutting glass, and the curved edges are best. Angles obtained by cleavage produce only a rough scratch, like quartz. Though the fissure made by the diamond in cutting glass is not more than the $\frac{1}{200}$ of an inch in depth, yet with a slight pressure on each side or a blow, it determines the course of the fracture through a very thick plate.

FIG. 190.

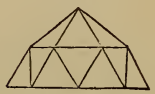
Diamond Crystal.

FIG. 191.

Brilliant.

**522. Diamond Cutting.**—Diamonds are so hard that they can only be cut or wrought by means of diamond powder. This fine dust is mixed with olive oil and spread upon a plate which is made to revolve two or three thousand times in a minute. The gem is soldered to an arm and pressed against the revolving disc by means of weights. In this way the diamond is cut into three forms—the *brilliant*, the *rose*, and the *table*, as shown by the accompanying figures. The brilliant is cut with a plane or table at the top, surrounded with facets. It is also cut with facets below, which are made at such angles to those above that the most perfect reflection is produced. The brilliant, there-

FIG. 192.



Rose Diamond.

FIG. 193.

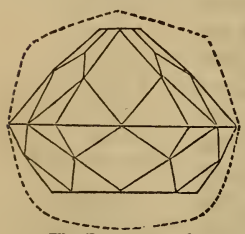
Table Diamond.

520. How may it be burned? Why has it been regarded as of vegetable origin?
521. Its uses? In cutting glass? 522. How are diamonds cut? Describe the bril-

fore, has the finest effect, but requires the sacrifice of the largest portion of the gem. A brilliant cut diamond is esteemed equal in value to a rough one of twice the weight, added to the cost of working it. The rose is cut into a hemispherical form with a pointed summit and 24 facets: it is flat beneath. Table diamonds are made from thinner specimens.

**523. Value of Diamonds.**—The weight and value of diamonds are reckoned by *carats* of four grains each. The average value of a perfectly cut diamond weighing one carat is $40. They increase in value, not in proportion to their weight, but to the *square* of their weight. The value of three diamonds weighing 1, 2, and 3 carats is as 1, 4, and 9. This rate of valuation, however, only applies to those of moderate size, as it would render the price of large diamonds so enormous as to place them beyond the reach of even the wealthiest.

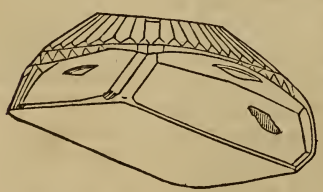
Fig. 194.



The Pitt Diamond.

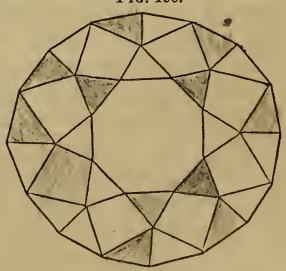
**524.** Of the largest, or, first class diamonds, there are but few; perhaps less than a score altogether. These have been so coveted by princes as to have figured quite prominently in oriental politics and diplomacy. Fig. 194 represents a diamond brought from India by a Mr. Pitt, and sold

Fig. 195.



Koh-i-noor, before cutting (*side view*).

Fig. 196.



After cutting (*upper face*).

to the Regent of France for $500,000. It is of a light blue color, and weighs 136 carats. The dotted line shows its form before cut-

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liant. The rose. The table. 523. How are the weight and value of diamonds estimated? 524. What does Fig. 194 represent? 195? What is its history?

ting. One of the largest diamonds is the *Koh-i-noor* (mountain of light), which came from India, and, according to native legends, was found 4,000 years ago. It has been in the hands of various families, and its possession has cost many murders and wars. It now belongs to the British crown. Fig. 195 represents the gem in its original shape and size. It was only surface-cut in the rose form. In 1852 it was cut into a brilliant weighing 162½ carats, after one third of it was removed. Fig. 196 represents its size and upper face. It took thirty-eight days to cut it, by steam, the operator working twelve hours a day without cessation.

**525. Graphite or Plumbago** is another allotropic form of carbon. It is found in beds in the earth, and crystallizes in six-sided plates of a metallic lustre, resembling lead; hence it is called *black lead*. Like the diamond, it resists the action of intense heat, and is useful to the chemist in making crucibles. It is friable, has an unctuous feel, and is used instead of oil, to relieve the friction of machinery. Being unaffected by the weather, it forms a valuable coating to protect iron-work from rust; and, as it resists heat, it is fitted for stove polish. It is, however, often adulterated largely with lampblack, which may be detected by heating the suspected sample to redness, when the lampblack burns away. Its most important use is in the manufacture of pencils. The powder being subjected to enormous pressure coheres into blocks, and is then sawed into thin slices, and again into small bars, which are placed in grooved cedar sticks for use. Though apparently so soft, the particles of graphite are extremely hard, and soon wear out the steel saws with which it is cut.

**526.** Graphite, unlike diamond, may be artificially produced. When cast-iron, which has been melted in contact with an excess of carbon, is allowed to cool slowly, the carbon crystallizes out in the form of graphite. In the manufacture of coal gas, a layer of pure dense carbon, having a metallic lustre, is deposited upon the hottest parts of the retort. It is called *gas carbon*, and seems a modification of graphite, if, indeed, it be not itself an allotropic form of carbon. Brodie has produced a compound called *graphic acid* ($C_{22}H_4O_{10}$), in which he considers the graphite as retaining its allotropic state, and he hence terms it *graphon*, with the symbol Gr.

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525. What is graphite? Its properties and uses? 526. How is it artificially pro-

527. **Charcoal** is the third well-studied allotropic variety of carbon. When any organic substance, as wood, bones, sugar, is burned, with a partial exclusion of air, a black mass remains which is known as charcoal. It is ordinarily prepared by covering large heaps of wood with tar, and burning them with a restricted supply of air, so as to prevent complete combustion, and only char the wood. The finer kinds of charcoal, such as are used for making gunpowder, are produced by distilling the wood in close iron retorts.

528. **Properties.**—Charcoal is a black, brittle, inodorous, tasteless solid; a good conductor of electricity, but a bad conductor of heat, and perfectly insoluble in all liquids. It is oxidized by strong nitric acid, but resists the action of air and moisture, and is, therefore, very unchangeable. The timbers, and grains of wheat and rye, converted into charcoal 1800 years ago, at Herculaneum, remain as entire as if they had been charred but yesterday. Wooden posts are hence rendered more durable by charring their ends before placing them in the ground. The interior of tubs and casks are often charred for the same reason.

529. The chief use of charcoal is as a fuel. When pure, it burns without flame, although it usually contains water which, during the combustion, is partially decomposed into carbureted hydrogen, and burns with a slight flame. A cubic foot of charcoal from soft wood, weighs from 8 to 9 lbs.; from hard wood, from 12 to 13 lbs.: hence, hard wood coal is best adapted to produce a high heat in a small space. At high temperatures, charcoal has a very powerful affinity for oxygen: therefore, it is of great value in reducing metals from their oxides, in the smelting furnace.

530. **Absorbent Powers of Charcoal.**—Having the structure of the wood from which it was derived, charcoal is very porous, and possesses in a remarkable degree, the power of absorbing gases, and condensing them within its pores. It will absorb 90 times its bulk of ammonia; 35 times its bulk of carbonic acid, and 9 times its bulk of oxygen. Freshly burned charcoal imbibes watery vapor from the air very greedily, and by a week's exposure, increases in weight from 10 to 20 per cent. Charcoal having the finest pores, possesses this power of absorption in the greatest

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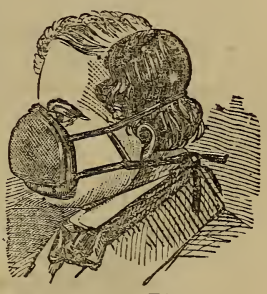
dized? 527. How is charcoal obtained? 528. What are its properties? Instances of its preserving action? 529. How does it burn? What kind makes the best fuel? How does it act in reducing metals? 530. What makes it so absorbent?

degree; the spongy sort least. 'A cubic inch of charcoal,' says Liebig, 'must have, at the least computation, a surface of 100 square feet.'

531. The power of porous bodies to condense gases (72), in the case of carbon is of great importance. Charcoal absorbs noxious gases and offensive odors; and, when crushed, foul water filtered through it, and tainted meat packed in it, are restored to sweetness. The charcoal from bones (bone black) is superior to wood charcoal for purifying purposes. It is extensively used in sugar refineries to decolorize syrups. Vinegars, wines, &c., are bleached in the same way.

532. **Charcoal not an Antiseptic.**—Charcoal is a powerful deodorizer, and disinfectant, but it is not an antiseptic, or preventor of change, as has been supposed. In fact, it is an *accelerator* of decomposition. It was formerly thought that charcoal acted by simply sponging up the deleterious gases, and retaining them in its pores; but it has been lately shown that, by means of its condensing power, it is a powerful agent of destructive change. The condensed oxygen seizes upon the other gases present, and oxidizing them, forms new products. It thus changes ammonia to nitric acid, and sulphuretted hydrogen to sulphuric acid. The body of a dead animal packed in charcoal, emits no odor, but instead of being preserved, its decomposition is much hastened. This property has been made medically available in the form of charcoal poultice, to corrode away sloughing and gangrenous flesh in malignant wounds and sores. The dark, carbonaceous matter of soils is thus not only a magazine for storing gases, but a most potent agency of chemical change.

Fig. 197.



Breath Filter.

533. **Dr. Stenhouse,** who in 1855 first drew attention to the septic powers of charcoal, has contrived ventilating arrangements in which the air of dwellings is filtered through it. He also invented a breath filter or respira-

Give examples. How much surface has a cubic inch? 531. How is this property utilized? What kinds are best? For what else is it used? 532. What is its relation to decay? How is this proved? Its use in medicine and in soils? 533. What

tor consisting of a hollow case of wire gauze fitted to the face, as shown in Fig. 197. It is filled with coarsely powdered charcoal, which strains the air of its impurities before it enters the lungs.

534. **Lampblack** is a modification of charcoal. It is the soot deposited from the burning of pitchy and tarry combustibles. The smoke is conducted through long horizontal flues terminating in chambers hung with sacking, upon which the lampblack is deposited. It is used for making printers' ink and black paint. In combustibility it stands at the opposite extreme from the diamond, and so great is the surface it exposes to oxygen, that it has been known to take fire spontaneously in the open air.

535. As in the diamond and graphite, the particles of the other varieties of carbon are extremely hard. Those of charcoal when rubbed between two plates of glass scratch it easily; while pieces of anthracite coal have been used to cut glass like the diamond. The mineral coals found in the earth are forms of carbon, and will be noticed in Organic Chemistry.

## § VII. *Compounds of Carbon and Oxygen.*

### CARBONIC ACID.

(*Carbonic Anhydride*, *Fixed Air*, *Mephitic Air*, *Choke Damp of Miners.*) *Sym.* $CO_2$. *Equiv.* 22. *Sp. gr.* 1,529.

536. All the forms of carbon when burned in the air unite with oxygen and form carbonic acid. This is a colorless gas with a slightly sour taste and about half as heavy again as air. It exists abundantly in the mineral crust of the globe, in the fixed or solid state, and was hence at first called *fixed air*. It exists also in a free condition in the atmosphere, where it is indispensable to the vegetable kingdom. It was first described by Dr. Black in 1757, and is remarkable as the first gas discovered.

Fig. 198.

Jar for making Carbonic Acid.

537. **Preparation.**—Carbonic acid exists in limestone to the extent of 44 per cent. of its weight, and is most conveniently obtained by the action of an acid upon powdered marble,

are Dr. Stenhouse's inventions? 534. What is lampblack? How obtained? Its properties? 535. What is said of the properties of carbon? 536. What is carbonic

or chalk. Any strong acid will answer the purpose, but chlorohydric is the best. The powdered mineral is placed in a jar and covered with water. A little dilute acid is then poured down through the tube, Fig. 198; effervescence immediately takes place, and the gas escapes through the bent tube. It may be collected over water in the pneumatic trough, or, as it is heavier than the air, it will quickly displace it in an open vessel. The change is thus shown:

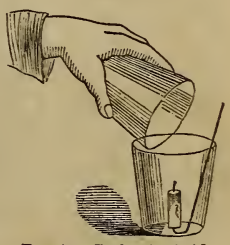
$$CaO, CO_2 + HCl = CaCl, HO + CO_2.$$

A cubic inch of marble will yield four gallons of the gas.

**538. Test.**—Carbonic acid combines with bases forming a class of salts known as the carbonates. Its test is solution of lime or clear lime water. When exposed to carbonic acid, it turns milky from the formation of insoluble carbonate of lime. Thus, if we expose a saucer of lime water to the air, in a short time its surface is covered with a thin film of carbonate of lime, proving that there is carbonic acid in the atmosphere. If we blow through a tube into a jar of lime water, it quickly becomes turbid from the same cause, thus showing that there is carbonic acid in the expired breath.

**539. It Extinguishes Fire.**—To prove this, and to show also that it is heavier than air, we have but to place a lighted taper in a jar, and pour in carbonic acid from another vessel, Fig. 199; the invisible current promptly puts out the light. It has been proposed to employ this gas on a large scale to extinguish fires. Some pulverized chalk and a bottle of acid are placed in a suitably constructed vessel, and when wanted for use, the bottle is crushed and the gas set free in large quantities. Such is the construction of the '*Fire Annihilator.*' This property of carbonic acid has been made available in extinguishing the accidental fires of coal mines. In one case an English mine had been on fire 30 years and burned a 9-foot seam of coal over an area of 26 acres, defying all efforts to quench it. Eight million

Fig. 199.



Pouring Carbonic Acid.

acid? Why was it called fixed air? When and by whom was it discovered? 537. How do we obtain it? What are the changes? 538. What are carbonates? What is its test? How do we prove its presence in the air? How in the breath? 539. What is shown by Fig. 199? What is the fire annihilator? Where has this

cubic feet of the gas were poured into it for three weeks day and night, and the fire was thus completely extinguished.

**540. Poisoning by Carbonic Acid.**—When respired, carbonic acid is fatal to life. If pure, it produces spasm of the glottis, closes the air passages, and thus kills suddenly by suffocation. When diluted with even ten times its bulk of air, and taken into the system, it acts as a narcotic poison, gradually producing stupor, insensibility, and death. This gas often accumulates at the bottom of wells, and in cellars, stifling those who may unwarily descend. To test its presence in such cases, it is common to lower a lighted candle into the suspected place, and if it is not extinguished, the air may be breathed safely for a short time. If the light goes out, it will be necessary before descending to let down dry-slaked lime, or pans of freshly burned charcoal to absorb the gas.

**541. Sources of Carbonic Acid.**—It is produced throughout nature on an immense scale. Oxygen of the air seizing upon the carbon of the organic world, whether in rapid burning, or slow decay, gives rise to this gas. The combustion of a bushel of charcoal produces 2,500 gallons of $CO_2$. It is produced by fermentation, and the slow decomposition of organic bodies, and also by the respiration of the entire animal world. Each adult man exhales about 140 gallons per day. It is also produced by decompositions and oxidations in the earth, and comes up with the waters which rise to the surface. It escapes in vast quantities from volcanoes, both active and extinct. Rising to the surface, often more rapidly than it is diffused into the air, it accumulates in invisible pools and ponds. Through the celebrated *Grotto del Cane*, in Italy, a man may walk unharmed, but a dog with its nostrils near the earth, is suffocated on entering. The poison valley of Java is a lake of carbonic acid, filled with the bleached bones of dead animals.

**542. Effervescent Drinks.**—The sparkling appearance and lively, pungent taste of various mineral waters are due to the carbonic acid they contain. Water absorbs nearly its own volume of carbonic acid, but by means of a forcing-pump it may be made to receive a much larger proportion. 'Soda water' is ordinarily

property been successfully used? 540. How does it act when breathed? What precautions should be taken? 541. What are the sources of carbonic acid? 542 What is said of $CO_2$ in mineral waters? In soda water? In fermented

only water charged with carbonic acid. Being overcharged, when the pressure is withdrawn, the gas escapes with violent effervescence. The effect is the same whether the carbonic acid is forced into the water from without, or generated in a tight vessel, as is the case with fermented liquors; the gas gradually formed is dissolved by the water, and, escaping when the cork is withdrawn, produces the fuming and briskness of the liquor.

**543. Its Liquid and Solid Forms.**—Under a pressure of 36 atmospheres at 32°, carbonic acid shrinks into a colorless, limpid liquid lighter than water. When this pressure is removed, it does not suddenly resume its gaseous state, but evaporates with such rapidity, that one portion absorbs heat from another, and freezes it to a white solid, like dry snow. This solid carbonic acid wastes away but slowly, and may be handled, though if it rests long upon the flesh, it disorganizes it like red-hot iron.

**544.** Unlike other acids, the carbonic does not unite with water to form a definite hydrate. As a gas, a liquid, and a solid, it is anhydrous, and the later school of chemists designates it constantly as *carbonic anhydride.*

**545. Carbonic Oxide,** CO, is a colorless, almost inodorous gas, which burns with a pale, blue flame. It is produced by burning carbon with an imperfect supply of air, and its formation may be observed in an open coal fire. At the lower part of the grate, where the air is abundant, carbonic acid is formed. As it ascends into the hot mass above, it loses half of its oxygen, becoming carbonic oxide. The liberated oxygen combining with the carbon of the fuel, also produces an equal quantity of the gas. As the carbonic oxide thus formed, rises to the surface of the fire, it burns to carbonic acid with a lambent, blue flame. This gas may be obtained pure and in great quantities by heating one part of prussiate of potash with ten of sulphuric acid, in a capacious retort. Carbonic oxide when respired, is still more deadly than carbonic acid.

## § VIII. *Compounds of Carbon and Hydrogen.*

**546.** These form an extensive and important group, but they belong chiefly to Organic Chemistry; two only will be here mentioned. These substances have long been regarded as only of

drinks? 543. How is solid carbonic acid obtained? 544. Why is it called carbonic anhydride? 545. When is carbonic oxide formed? Its properties when respired?

organic origin, but BERTHELOT has lately succeeded in producing them by the direct union of their elements.

**547. Light Carburetted Hydrogen,** $C_2H_4$.—(*Marsh Gas, Fire Damp.*) This is a colorless, inodorous, tasteless, inflammable gas, which burns with a yellow, luminous flame. If diluted with air, it is not injurious to life. It may be produced by heating in a glass flask, a mixture of two parts of acetate of soda, three parts of caustic potash, and three of quicklime. It is called marsh gas, because it is a product of the decomposition of vegetal matter contained in the mud of stagnant pools. It may be collected by inverting a jar and funnel in the water, and stirring the mud beneath, Fig. 200, when the gas rises into the jar in bubbles. It is often disengaged in large quantities in coal mines: mixed with the air it becomes explosive, and constitutes the fatal *fire damp.* If the air is more than six times or less than fourteen times the bulk of the gas, the mixture explodes violently. Carbonic acid is produced by the combustion, so that those who are not killed by the burning or shock, are generally suffocated by the choke damp.

FIG. 200.

Procuring Marsh Gas.

**548.** In some places, this gas rises from the earth in such quantities, as to be utilized for purposes of illumination; as in the village of Fredonia, N. Y. In the deep wells sunk for brine and mineral oil, it often rises in such quantity as to be employed for driving the pumping engines, or for evaporating the liquids.

**549. Olefiant Gas,** $C_4H_4$ (*Ethyline*).—This gas may be prepared by mixing strong alcohol with five or six times its weight of sulphuric acid in a retort, and applying heat. It is colorless, tasteless, nearly as heavy as air, with a marked odor, very inflammable, and burns with a bright and intensely luminous flame. When mixed with air, it is explosive, and derives its name (oil-former) from the circumstance of its forming an oily compound with chlorine. It was liquefied by FARADAY under great pressure.

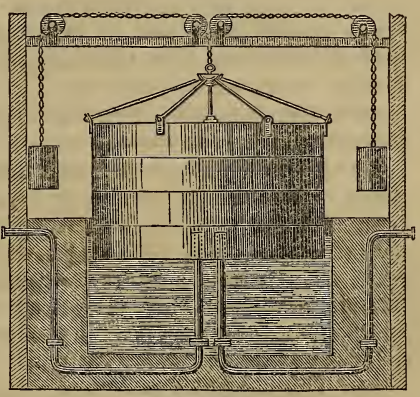
546. Are the hydro-carbons always of organic origin? 547. What is light carburetted hydrogen? How is it obtained? Why called marsh gas? What is fire damp? 548. Other natural sources? 549. What are the composition and

It is decomposed by electric sparks, depositing half its carbon, and forming light carburetted hydrogen.

**550. Illuminating Gas** consists chiefly of the foregoing compounds of hydrogen and carbon. It is commonly produced from bituminous coal, by heating it in cast iron retorts, which are fixed in furnaces, and heated to redness by an external fire. Each retort receives a charge of 100 to 150 lbs. of coal every six hours, and in large gas works, several hundreds of them are kept at work day and night. At a moderate heat, tar and oil are produced (957), but at a high temperature, gases are formed in large quantities. The principal products of this destructive distillation are a thick, black liquid, known as *coal-tar*, steam, various compounds of ammonia, sulphide of hydrogen, carbonic acid, light, carburetted hydrogen, olefiant gas, and a solid, friable, carbonaceous mass known as *coke*.

**551. How Purified.**—This heterogeneous mixture is wholly unfit for illuminating purposes till purified. The liquid and gaseous products, as they are set free, flow out from the retort, through a tube into a receiver, called the *hydraulic main*, in which the tar and ammoniacal liquor are to a great extent separated from the gaseous products. But being hot, they still retain various matters in a vaporous state, which would be deposited, and clog the gas pipes; these are still farther separated by passing through the *condenser*, which consists of iron tubes surrounded by cold water. The gas is then passed through a mixture of lime and water (milk of lime), or through layers of

FIG. 291.



The Gasometer.

properties of olefiant gas? 550. What is illuminating gas? How is it produced? What other products result? 551. How is the gas purified? Describe the gas-

damp slaked lime, which absorbs the carbonic acid and sulphide of hydrogen. It is then sometimes freely washed with water, which removes all its ammonia, when it is transmitted to a large storing vessel called the *gasometer*, Fig. 201. This is an immense sheet iron cylinder, open at bottom, and closed at top, which floats in a cistern of water. Two pipes open into the interior, one to deliver the purified gas which fills and raises the gasometer, and the other, which is connected with service pipes, to convey it away for consumption. The gasometer is balanced by weights which are so graduated as to compress the gas sufficiently to force it through the pipes to the farthest points desired.

**552. Composition.**—This is variable, but it mainly consists of olefiant gas, light carburetted hydrogen, carbonic oxide, vapors of benzole and naphtha (958), with free nitrogen and hydrogen. Its value depends upon the proportion of olefiant gas, which is the chief light-producing compound. This is obtained first, and diminishes as the charge of coals is protracted, the poorer light-giving materials increasing. In one case, the gas first delivered contained 13 per cent. of olefiant gas, 82 of carburetted hydrogen, 3.2 of carbonic oxide, and 1.3 of nitrogen. After 10 hours, it yielded 20 parts carburetted hydrogen, 10 parts of carbonic oxide, 60 of hydrogen, and 10 of nitrogen.

**553. Gas from other Sources.**—Crude, refuse oil, which is unfit for burning, is sometimes converted into gas by being made to trickle into a retort, containing fragments of coke, or bricks heated to redness. It contains no sulphur products, needs no purification, and is rich in olefiant gas. Resin, by being melted and treated in a similar way, yields a superior gas. An excellent gas is also produced from the distillation of wood; but in point of economy, none of these sources can compete with coal. A pound of coal yields from three to four cubic feet of gas; a pound of oil, 15; of tar, 12; and of resin, 10.

**554. Extent of its Use.**—Illuminating gas has come into use entirely within the present century. It was first employed in London, in 1802, and its use has extended until nearly 500,000 tons of coal are consumed in a year by the establishments of that city alone.

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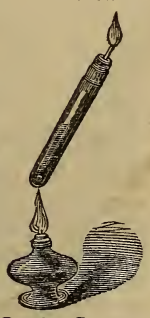
ometer. 552. Upon what does the value of the gas depend? How do the proportions differ at different stages of the distillation? 553. What is said of gas from other substances? Its economy? 554. When and where was illuminating gas first employed? How much is now consumed there? What thought is suggested?

producing 5,000,000,000 cubic feet of gas, and yielding an amount of light which would be equal to that given by ten thousand million tallow candles, six to the pound. How wonderful that sunbeams absorbed by vegetation in the primordial ages of the earth, and buried in its depths as vegetable fossils through immeasurable eras of time, until system upon system of slowly formed rocks have been piled above, should come forth at last, at the disenchanting touch of science, and turn the night of civilized man into day!

## § IX. *Compounds of Carbon and Nitrogen.*

**555. Cyanogen**—*Symbol*, Cy.—Carbon and nitrogen do not unite directly; but if animal matter, such as hides, horns, parings of hoofs, &c., be heated in a covered iron pot with carbonate of potash and iron filings, the carbon and nitrogen, as they are set free, combine to form a compound known as *cyanogen*, $NC_2$. This substance was discovered by Gay Lussac in 1814, and is remarkable as being the first chemical compound known to play the part of an element. Cyanogen proved to be an electro-positive body which would combine directly with the metals, like chlorine. It was, therefore, called a *compound radicle*, and represented by the symbol, Cy. The doctrine of compound radicles has been since extensively carried out (910). When produced as above, cyanogen unites with potassium and iron, producing the salt ferro-cyanide of potassium, $K_2FeCy_3, HO$, which forms the splendid yellow crystals of commerce. The word cyanogen signifies *blue producer*, as it is a constituent of the pigment prussian blue.

Fig. 202.



Burning Cyanogen.

**556.** Cyanogen is a transparent, colorless gas, poisonous if respired, and with a strong odor. It is very soluble in water, and hence must be collected in the pneumatic trough over mercury. It is reduced to a colorless, limpid liquid by a pressure of four atmospheres, and freezes into a transparent crystalline solid at 30°. It may be best procured in small quantities by heating a little cyanide of mercury in a test tube, Fig. 202. The salt is decomposed, the gas escapes,

555. How may carbon and hydrogen be made to unite? For what is cyanogen remarkable? What doctrine has this led to? Meaning of the word? 556. What

and when ignited, burns with a beautiful blue flame edged with purple. *Paracyanogen* is an insoluble isomeride of cyanogen.

557. **Cyanohydric Acid,** HCy. (*Hydrocyanic Acid, Prussic Acid.*)—This is a colorless, transparent liquid, and so volatile that a drop on the end of a glass rod in the air solidifies by its own evaporation. It may be obtained by decomposing a salt of cyanogen with strong acid, and then distilling it, the vapor having the odor of peach blossoms. It is one of the most insidious and deadly poisons, a few drops producing death in a few seconds. This acid is obtained by distillation of the kernels of bitter almonds and various fruits, and also from the leaves of the laurel, peach, &c.

558. Cyanogen forms several compounds with oxygen, the best known of which are *cyanic acid* and *fulminic acid*. The latter combines with metals, forming fulminates which are violently explosive. *Hydrated cyanic acid* is a volatile and highly corrosive fluid, which cannot be brought into contact with water without being instantly decomposed. *Cyanuric acid* is crystalline, soluble in water, and forms salts with metallic oxides. *Cyamelide* is a white, porcelain-like substance, absolutely insoluble in water. Yet these bodies are all isomeric, and may be converted into each other without loss or addition of constituents.

## CHAPTER VIII.

### THE ATMOSPHERE.

### § I. *Its Physical Properties.*

559. This is the thin, gaseous medium which surrounds the globe. It is considered under a twofold aspect—in its mass, or as manifesting physical properties, and in its composition or chemical relations. The first belongs properly to Natural Philosophy, but it will be useful to recall a few points which are of constant appli-

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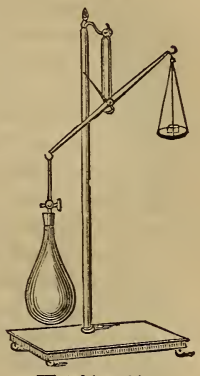
are the properties of cyanogen? How is it obtained? 557. What is cyanohydric acid? How obtained? Its properties? Where is it found? 558. What compounds does cyanogen form with oxygen? What are fulminates? Properties of hydrated cyanic acid? Cyanuric acid? Cyamelide? What is said of these substances? 559. Under what aspects may the air be considered? 560. What is the

cation. We have deferred the subject to this place, that the student may be familiar with the atmospheric constituents.

**560. Weight of Air.**—It was first discovered about 200 years ago that air, like all other forms of matter, has weight. If a light flask be exhausted, and then carefully counterpoised at the balance, when the air is let in, it will become heavier and sink, Fig. 203. A cubic foot of air weighs 538 grains, or something more than an ounce, and a room 40 feet square and 18 feet high contains about a ton.

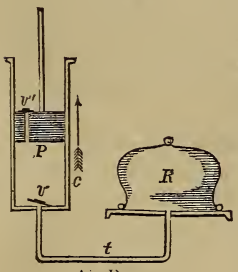
Fig. 203.



Weighing Air.

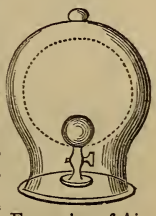
**561. The Air Pump** is an instrument for exhausting air from a tight vessel. In Fig. 204, $P$ represents a piston which works air-tight in the cylinder $c$, and $v$ $v'$ are valves of leather or silk which guard openings in the piston and the bottom of the cylinder. As the piston descends, $v$ opens while $v'$ shuts. The tube $t$ connects the pump with the receiver $R$, which loses a portion of its air at each stroke. The receiver is a large glass vessel ground flat at the bottom so as to rest air-tight upon the pump plate. As its name implies, it *receives* objects for experiment.

Fig. 204.




Air Pump.

Fig. 205.



Expansion of Air.

**562. Elasticity.**—If a small tight india rubber ball containing air be placed within the receiver and exhaustion take place, the air within will be dilated with force, and the ball will expand to several times its original size, as shown by the dotted line, Fig. 205. If the receiver be opened, the air rushes in, and the ball returns to its original dimensions. At first the air without and within the ball press against each other *equally*, but

weight of the air? 561. Explain Fig. 204 What is the receiver? 562. Describe

when the outside pressure is withdrawn, the air within, by its inherent elasticity, expands into a larger bulk. Air exists in the pores of bodies, and by taking off the pressure, it expands and escapes. This is shown in Fig. 206, which represents an egg in a glass of water under an exhausted receiver.

Fig. 206.

Egg in Receiver.

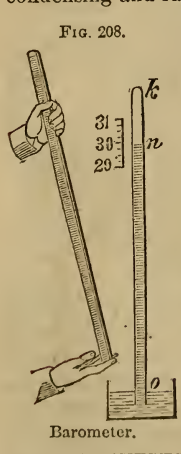
**563. Atmospheric Pressure.**—As the air has weight, it of course exerts pressure upon surrounding objects. This pressure is in all directions, downward, sidewise, and upward. If a wine glass be filled with water, a card placed upon it, and then inverted, the upward pressure of the air supports the liquid in the glass, Fig. 207. This pressure is considerable. If the hand be placed over the open end of a glass and the air be exhausted, it will be held as if with a powerful weight. The weight, or pressure of the air at the level of the sea, is 15 lbs. on every square inch; this is, therefore, called an *atmosphere:* 30 lbs. would be two atmospheres, and 1,500 lbs. a hundred atmospheres.

Fig. 207.

Upward Pressure of Air.

**564.** The weight of the air is not the same at all times. Winds and storms keep it in motion, condensing and rarefying it, and thus affecting its pressure. There are also tides in it as in the ocean—great atmospheric waves, which sweep over the earth, and with these movements, the pressure constantly varies.

Fig. 208.




Barometer.

**565. The Barometer.**—Variations of pressure are measured by the *barometer.* To make this instrument, a glass tube is taken, 33 or 34 inches long, closed at one end, and filled with quicksilver. It is then closed with the finger, as shown in Fig. 208, inverted, and its open end plunged into a vessel of quicksilver, *o.* The mercury then falls from *k* to *n*, leaving a vacuum, or place of no pressure in the upper end of the tube. The weight of the air pressing upon the mercury in the cup, supports the mercurial column 30 inches high. But as the atmospheric

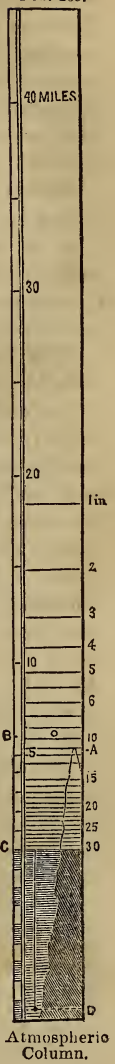
the experiment, Fig. 205. What property of the air is here shown? What is

pressure varies, the column rises and falls along the scale of some $2\frac{1}{2}$ inches, attached to the tube.

**566. Pressure upon the Human Body.**—Upon the body of a medium sized man, having a surface of 2,000 square inches, the atmosphere exerts a crushing force of 30,000 lbs., while the variation of an inch in the barometric column corresponds to a variation of 1,000 lbs. pressure upon the body. That we are not conscious of this pressure is, because the air within us presses outward with equal force. By ascending a mountain till the mercurial column fell to 14 inches, and by descending in a diving bell till it rose to 45 inches, HUMBOLDT exposed himself to a variation of 31 inches, or 31,000 lbs. of pressure upon his person.

**567. Rarefaction in the Higher Regions.**—As we rise from the surface of the earth, we leave a portion of the atmosphere below us, and the weight of that above, of course, decreases. Elasticity then comes into play; under less pressure the air expands, and as we ascend, it grows more and more rare, the barometer falling in exact proportion. Fig. 209 is designed to represent a vertical section of the atmosphere, extending upward about 45 miles. The left hand column of numbers shows the height in miles above the sea level; the right column the corresponding height of the barometer in inches. A, indicates the height of the highest peak of the Himalaya Mountains. The small circle marks the greatest height reached by a balloon (six miles), by Mr. GLAISHER, in 1862; C, the sea level, and D, the deepest soundings yet obtained (by Capt. DENHAM, $8\frac{3}{4}$ miles).

FIG. 209.




## § II. *Chemical Constituents of the Air.*

**568.** The atmosphere is a mixture of several gases; nitrogen and oxygen constituting its bulk. There is a small proportion of carbonic acid and watery vapor, and variable traces of other substances. According to DUMAS and BOUSSINGAULT, its average composition by volume is 20.81 of oxygen, and 79.19 of nitrogen, in

shown by Fig. 206? 563. How is the pressure of the air shown? How much is it?

10,000 parts, or by weight 23.01 of oxygen, and 76.99 of nitrogen. This was ascertained by passing a stream of air slowly over a weighed quantity of heated copper in a tube. The oxygen was absorbed by the copper, the gain in weight of the tube indicating its quantity. The nitrogen was received into an exhausted flask, which was weighed before and after the experiment. The proportions of these two gases in the atmosphere are nearly invariable.

669. If an artificial mixture of four parts nitrogen and one part oxygen be made, a candle will burn in it, and animals breathe in it as in ordinary air. The atmosphere is not a chemical compound, but a *mechanical mixture;* its constituents being diffused throughout each other according to the great law of gaseous intermixture (74).

570. The proportion of watery vapor in the atmosphere varies with the temperature. It usually ranges from the $\frac{1}{60}$ to the $\frac{1}{200}$ of the bulk of the air. By passing known quantities of air through carefully weighed tubes of caustic potash, the carbonic acid is absorbed, and its proportion determined. It varies from 3 to 6 parts in 10,000 of air, and averages about one volume in 2,500. The quantity is variable within the limits above stated. It increases as we rise from the earth, and is less after a rain, which washes it down from the air; it increases during the night, and diminishes after sunrise, is less over large bodies of water than over large tracts of land, and is more abundant in the air of towns, than in that of the country. Traces of nitric acid, ammonia, and carburetted hydrogen are also invariably present, and in the air of towns, sulphuretted hydrogen, and sulphurous acids.

571. **Proportions of the Atmospheric Elements.**—A very clear idea of these quantities may be gained by supposing the air throughout to be of a uniform density, and its elements separated into strata, in the order of their specific gravities. In such a case the air would extend to the height of about five miles (GRAHAM).

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it? What is this called? What of its variability? 565. What is the barometer? How is it made? What causes the height of the column to vary? 566. What is the pressure upon the body of a medium sized man? To what variations did HUMBOLDT expose himself? 567. What is Fig. 209 designed to represent? 568. What is the composition of the air? How was it ascertained? 569. What is the state of its elements? 570. What is the proportion of watery vapor? How is the carbonic acid determined? Where is it most abundant? Of what other substances are traces found? 571. How may we get a clear idea of these quantities?

Its greatest quantity of watery vapor, if condensed, would form a stratum of water about 5 inches deep; the layer of carbonic acid would be about 13 feet deep; that of oxygen about 1 mile, and that of nitrogen about 4 miles in depth.

**572. Resulting Properties.**—Each of the constituents of the air is essential to the present order of things. We have seen how imposing is the part played by oxygen, which is preëminently its active element. To duly restrain this activity, the oxygen is diluted and weakened by four times its bulk of the negative element, nitrogen. Their properties are thus perfectly adjusted to the requirements of the living world. Were the atmosphere wholly composed of nitrogen, life could never have been possible; were it to consist wholly of oxygen, other conditions remaining as they are, the world would run through its career with fearful rapidity; combustion once excited, would proceed with ungovernable violence; animals would live with hundred fold intensity, and perish in a few hours.

**573. Offices of Watery Vapor.**—These are numerous and important in a high degree. Three fourths of the weight of plants and animals consist of water, and they are continually absorbing and exhaling it; while the rate of this vital operation depends upon the degree of moisture in the air. Were it perfectly dry, evaporation from leaves would proceed faster than supply from the roots, and the plant would quickly wither and die. A man weighing 154 lbs. contains 116 lbs. of water. In absolutely dry air, he would quickly exhale this from skin and lungs, exhaust the tissues of their fluids, and shrivel to a mummy.

FIG. 210.

Formation of Clouds.

**574. Its Precipitation.**—When two currents of air of different temperatures, saturated with moisture, meet and mingle, the resulting mean temperature falls below the point necessary to hold all the water in a state of vapor, therefore a portion of it must

572. If the proportion of oxygen were increased, what would follow? 573. Were

fall. A gentle precipitation produces clouds, a more rapid one, rain. Thus, southerly winds loaded with humidity, coming in contact with the colder air of northern latitudes, usually give rain. For the same reason, the contact of air in motion with the cold surface of the earth, causes precipitation. This accounts for the fact that a larger amount of rain falls near the ground, than in the higher regions of the atmosphere. So currents of warm air striking against the side of a mountain are cooled, and, as they rise, produce the clouds and excess of rain which are peculiar to mountainous regions. In Fig. 210, the arrows show the course of the air currents, and the effect when they strike a mountain.

**575.** When we remember that all the moisture which the atmosphere could hold, would make a sheet of water only 5 inches thick—no more, perhaps, than is annually deposited as dew, we can only be amazed at the vastness of the effects which it produces in nature. So rapid and constant is the evaporation, that many times this quantity is precipitated in the course of a year. The amount of rain deposited is greatest at the equator, and diminishes toward the poles.

**576. The Carbonic Acid** which is poured into the atmosphere in prodigious quantities and from innumerable sources, is as necessary to the vegetable world, as is oxygen to the animal world. It is absorbed by the leaves, and minute as is its proportion, if it were withdrawn, the vegetable world would quickly perish.

**577. Liebig** has shown that the air contains minute traces of ammonia, which are washed down, and may be detected in rain-water. Traces of nitric acid have also been frequently detected. This substance is thought to be formed by electricity, every flash of lightning which darts across the sky combining a portion of the oxygen and nitrogen along the line of its course, and forming this acid. The saline particles of the ocean-waves, as they are dashed into foam and spray, are carried by the winds far inland. All these substances are brought down by the rains, and aid to quicken the growth of vegetation. The odorous

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the air dry, what would follow? 574. What is the cause of clouds and rain? Why is there excess of rain near the ground, and on the mountain sides? 575. What is said of the fall of rain? 576. What is the office of carbonic acid in the air? 577. Whence come the ammonia and nitric acid of the atmosphere?

emanations of flowers, the miasms of marshes, and principles of contagion, though all producing effects upon the human body, cannot be collected from the air, and not unfrequently elude the most delicate chemical tests.

**578. The Atmosphere and the Living World.**—The relations of the atmosphere to living beings, the stability of its composition, and the wonderful forces that are displayed within it, have been but lately unfolded by science, and are full of surpassing interest. The vegetable world is derived from the air; it consists of condensed gases that have been reduced from the atmosphere to the solid form by solar agency. On the other hand, animals, which derive all the material of their structure from plants, destroy these substances while living, by respiration, and when dead, by putrefaction, thus returning them again in the gaseous form to the air from whence they came. In respect to air, the offices of plants and animals antagonize. What the former derives from the air, the latter restores to it, thus maintaining its equilibrium and permanence. We shall return to this subject again in Physiological Chemistry.

## CHAPTER IX.

### COMBUSTION AND ILLUMINATION.

### § I. *Historic Notice—Phlogiston.*

**579.** By the ancients fire was considered one of the four elements of nature—the most pure and perfect of them, which tended forever upward to its own place, the *empyrean*—the highest heaven of pure fire and light. This doctrine held undisputed sway, so long as nature was not made a subject of experimental inquiry. But after a long period of laborious research on the part of the alchemists, a new order of facts was discovered, and a more definite theory of the cause and nature of fire was demanded. Accordingly about the middle of the 17th century, the German chemist, Beccher, propounded a new hypothesis of com-

What other substances are mentioned? 578. What is the relation of the atmosphere to living beings? 579. What was the ancient theory concerning fire? What

bustion, which was further illustrated by his eminent countryman, STAHL, toward the close of the same century. This was the *Phlogistic Hypothesis.*

**580. How Combustion was Explained.**—This doctrine assumed the existence of a rare ethereal principle called *phlogiston*, which could not be isolated, but existed in all bodies capable of burning. In the act of combustion phlogiston *escaped*, and the burning was caused by its escape. The products of combustion, which were deprived of phlogiston, and all bodies incapable of burning, were said to be *dephlogisticated.* When PRIESTLEY had discovered oxygen, which produced intense combustion, he believed that it acted by powerfully attracting the phlogiston of combustible bodies, and hence named it *dephlogisticated air.*

**581. Difficulties of the Idea.**—The fact that the metals when burned were changed to rust or cinders, was explained on the supposition that they consisted of this rust, or *calyx* as it was called, and phlogiston; when they were burned, phlogiston escaped, and the cinders were left. But at length it was observed that the calyxes were *heavier* than the metals from which they were produced; how then could they have *lost* anything? The hypothesis, however, was sufficiently elastic to cover this objection: it was replied that phlogiston was a principle of *levity* buoying up the substances with which it was associated, so that when it escaped, they became heavier. But the facts were no longer manageable by the hypothesis.

**582. Its Abandonment.**—The discovery of oxygen, and the introduction of the balance (48), by LAVOISIER, of France, gave the death blow to phlogiston. The general loosening of old ideas which marked the period of the French Revolution, was eminently favorable to scientific changes, and an improved system of chemistry was introduced, which was the more cordially welcomed that it was clothed in the simple and rational attire of a new and admirable language. In accordance with the dramatic spirit of the times, at a festival, 'Madame LAVOISIER, robed as a priestess, committed to the flames on an altar, while a solemn requiem was chanted, the phlogistic system of chemistry.' The new doctrine of the chemistry of oxygen was, therefore, at first known as the French system. The effect of the

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led to its overthrow? 580. What was the phlogistic theory? 581. How did it fail?

new language was, in a great degree, to break connections with the past, and has, perhaps, led those who came after, to undervalue the labors of the earlier chemists.

583. Phlogiston served an important purpose in its day, and it scarcely becomes us to ridicule the doctrine, since we of the present, with our better light, are by no means exempt from the charge of entertaining ideas quite as absurd. Sir DAVID BREWSTER remarks: 'As to the generic idea of phlogiston, erroneous though it was and is, it is extant in science yet; for it is impossible to see wherein *caloric* differs from it as a scientific conception, although elaborated with immensely greater precision, except that caloric is the matter of *heat*, while phlogiston is the matter of *fire*. Both phlogiston and caloric are substances which have no existence whatever in the external world; they have both been convenient, though fictitious representatives of natural realities, and they have both been eminently useful in standing for certain phenomena in their several days, but the latter creation of the materializing tendency of unripe science, is not a whit better in essence than the former.'

## § II. *Combustion and Heat.*

**584. Combustion a Chemical Process.**—Combustion in its popular sense, is that form of chemical action which is accompanied by the disengagement of heat and light, and which usually takes place between the oxygen of the air, and certain organic bodies, as wood, coal, oil, &c. The chemist, however, gives to the term a wider meaning, which includes all degrees of oxidation; the violent burning of iron in oxygen, or its slow rusting in the air; the rapid consumption of wood in the furnace, or its gradual decay; the vital process of animal respiration, by which oxygen is changed to carbonic acid in the living body, and warmth produced, are all alike, to him, cases of combustion.

585. It is an interesting circumstance that other cases of chemical action are brought about for the sake of the products formed, but in combustion the products are disregarded as worth-

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582. What led to its abandonment? What is said of this change? 583. To what is the theory of phlogiston compared? 584. What is the common idea of combustion? That of the chemist? 585. How does it differ from other cases of chemical

less, and the operation valued solely on account of the forces which are its incidental result.

**586.** Bodies were formerly divided into *combustibles* and *supporters of combustion.* Atmospheric oxygen was held to be a supporter of combustion, while hydrogen, carbon, and iron, which burn in it, were called combustibles. But, if the conditions of the experiment Fig. 177 be reversed—that is, if a jet of oxygen be ignited in an atmosphere of hydrogen—precisely the same effect will take place; oxygen will then be the combustible, and hydrogen the supporter of combustion. The fact is, the action is mutual, and of the same kind on the part of both elements; the distinction is therefore groundless.

**587. The Process Self-supporting.**—Every combustible substance requires a certain elevation of temperature in order to ignite, and the maintenance of this temperature is essential to the continuance of the combustion. After a substance is once kindled, the heat given off by the rapid chemical action is usually more than sufficient to maintain the combustion until the burning body is consumed.

**588. Cause of the Heat.**—It has been explained that chemical action produces heat by conversion of the motion of chemical atoms into heat vibrations. We have atoms separated and powerfully attracted, like lifted weights: they rush together, collision arrests motion, and their force is given out as heat. It is the clash or impact of the atoms of oxygen against the elements of burning bodies, which gives us the heat and light of combustion. By figuring to ourselves the atoms shot across the molecular spaces with intense force, and thus parting with their excess of motion, we have an explanation of the source of heat in combustion, which is in harmony with our latest knowledge of the nature of heat, and of its other modes of production, while in no other way is it possible to explain its chemical origin.

**589. Upon what the Amount of Heat depends.**—In all ordinary cases of combustion, the amount of heat set free depends upon the quantity of oxygen brought into action, rather than on that of the body burned. Hence, the combustible which unites with the most oxygen while burning, will give off the most heat.

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action? 586. What old distinction is said to be erroneous? 587. Why must combustion be first kindled? 588. What causes the heat and light of combustion? Describe the conception. 589. Upon what does the amount of heat

Thus, hydrogen in burning, takes up weight for weight three times as much oxygen as carbon does; consequently, it gives off three times as much heat.

590. The complete burning of a combustible body requires the consumption of the same quantity of oxygen, whether the process goes on rapidly or slowly, and, in either case, the amount of heat set free is the same. Therefore, the intensity of the heat depends upon the rapidity of the combustion. Heat would be liberated from the burning of a pound of coal in ten minutes, six times as fast as if its combustion occupied an hour. This is the reason why the smith blows his fire, and why such powerful blowing apparatus is applied to blast furnaces; they diminish the time of the combustion, and correspondingly increase its vehemence. The powerful blast or dräft also serves to expel from the fire the products of combustion which would impede it if suffered to accumulate. Yet excess of air is detrimental to the burning process, by conveying away heat, thus cooling the fuel, and checking the rate of combustion.

591. One pound of wood charcoal will raise from the freezing to the boiling point 73 lbs. of water; 1 lb. of mineral coal will correspondingly heat 60 lbs. of water, and 1 lb. of dry wood will raise 35 lbs. of water through the same number of degrees. These are the highest results by careful experiments; in practice we obtain a much lower effect, both on account of imperfect combustion, and from the fact that a large proportion of the heated air escapes through the chimney, before it has given off as great an amount of heat as it is capable of producing. The weight of air required to burn the fuel, is vastly greater than that of the fuel itself. It takes 11.45 lbs. of air to consume 1 lb. of charcoal, and as 1 lb. occupies nearly 13 cubic feet of space, the pound of charcoal will require about 150 cubic feet of air for its combustion.

592. **Kindling Temperature.**—The temperature at which oxygen goes into rapid combustion, differs with different bodies. Thus phosphorus ignites at 150°; sulphur at 480°, while the hydrocarbons require a temperature of nearly 1000° to kindle them. The stability of the order of nature depends upon the gradation

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depend? Example. 590. Its intensity? How is this illustrated? How may excess of air be detrimental? 591. Compare the heating effects of charcoal, mineral coal, and wood. How much air is required to consume 1 lb. of charcoal? 592. How do kindling temperatures vary? How has the art of kindling fires pro-

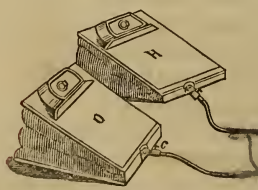
of the affinities between atmospheric oxygen, and the hydrogen and carbon of organic bodies. These are only brought into action at high temperatures. Did these bodies ignite at a much lower degree, like phosphorus, conflagrations, which are now comparatively rare, would become universal. To 'make a fire,' requires an effort of reason, and, like the other arts, it has progressed with the advance of thought. First, the friction of pieces of wood; then flints, steel, and tinder; and, lastly, with the progress of chemistry, phosphorized matches, the very perfection of convenience.

## § III. *Flame and Illumination.*

**593. Nature of Flame.**—Flame is produced by the combustion of gases, and is, hence, fire in motion. Substances which burn with flame, are either gases already, or they contain a gas which is set free by the heat of combustion. But flame does not necessarily produce light. In the burning of pure oxygen and hydrogen, there is intense flame, but so little light that it can hardly be seen. If, into this non-luminous flame, we sift a little charcoal dust, the particles of solid carbon are instantly heated to incandescence, and there is a bright flash of light. The conditions of illumination are, therefore, first, an intense heat, and, second, a solid placed in the midst of it, which remains fixed, and gives out the light.

**594. The Compound Blowpipe.**—These conditions are fulfilled most perfectly by means of the compound blowpipe of Dr. Hare.

Fig. 211.




Gas Bags for Blowpipe.

The two gases are collected in gasometers, or more conveniently in india-rubber bags, Fig. 211, which are connected by flexible tubes with the brass jet, Fig. 212; the flow being increased by pressure on the bags and controlled by stop-cocks. The gases are emitted together and burned at the orifice, *a*. When ignited, they produce a blue flame which is hardly visible, but which has intense heating power, and produces the most

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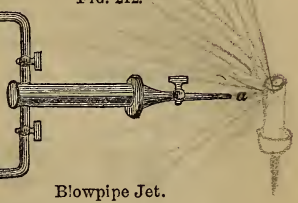
gressed? 593. What is flame? What substances produce it in burning? What causes the light? What are the conditions of illumination? 594. Describe the

remarkable effects. Very fine wire twisted together, or a steel watch-spring, burns with a shower of scintillations. Substances which do not fuse in the hottest blast furnaces melt in this heat like wax, or dissipate in vapor.

Fig. 212.




Blowpipe Jet.

**595. The Lime Ball.**—A little ball of lime, however, of the size of a pea, remains unaltered in the flame. It glows with a blinding brilliancy, producing what is known as the 'Drummond light,' the 'Lime light,' or the 'Calcium light.' It is employed as a substitute for the rays of the sun in the solar, or oxyhydrogen microscope, and is used in coast surveys for night signals. When reflected by a parabolic mirror in a pencil of parallel rays, it has been recognized in daylight at a distance of 108 miles. The hydrogen may be replaced without much disadvantage by ordinary coal gas.

**596.** In all ordinary illuminations the principle is the same as that of the lime light. The substances employed are hydrocarbons: the union of oxygen and hydrogen gives rise to heat, and the carbon particles at the same time set free in the heated space and made luminous, are the source of the light.

**597. How the Candle Burns.**—The materials used for illumination, whether solids or liquids, are always converted into gas before burning. The candle first becomes a lamp, and then a gas burner. When lit, the heat radiates downward, so as to melt the material of the candle and form a hollow cup filled with the liquid combustible, Fig. 213, and thus the candle becomes an oil burner. From this reservoir, the wick draws up the oil into the flame. Here, in the midst of a high heat, and cut off from the air, it undergoes another change exactly as if it were enclosed and heated in a gasmaker's retort; it is converted into gas, and in this form finally burned. As the wick rises into the flame, it fills the interior as a sooty mass, and interferes with the combustion. To avoid this, wicks are sometimes plaited or twisted, so that

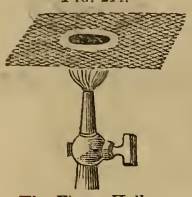
Fig. 213.

Burning Candle.

compound blowpipe. Its effects. 595 What is the Drummond light? 596. What is the principle of ordinary illumination? 597. Explain the process of burning a

in burning they bend over to the side of the flame, and are consumed.

Fig. 214.



The Flame Hollow.

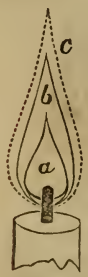
Fig. 215.

Gas from Flame.

**593. Structure of the Flame.**—As the wick remains thus unconsumed in the interior of the flame, it is obvious there can be no fire there. If we lower a piece of glass or a wire gauze over a candle or gas flame, as in Fig. 214, we shall see an interior dark space surrounded by a ring of fire. This inner sphere is filled with dark unburned hydrocarbon vapors, which are enclosed by a shell of fire, or burning gas. If one end of a small glass tube be introduced into the candle flame, as in Fig. 215, these interior gases will be conveyed away, and may be lit at the other end.

**599. Order of the Combustion.**—There is an order of combustion in the flame, which depends upon the order of affinities, and this is the hinging fact of illumination. In Fig. 216, *a* represents the nucleus of hydrocarbon vapor. If now oxygen from without had the same affinity for both its elements, they would be consumed together, with but little luminous effect. But the oxygen decomposes the gaseous compound, and, seizing upon the hydrogen first, surrounds *a* with the intensely heated space, *b*. At the same time the carbon particles are set free, and being heated white-hot, give out the motion of light. The cone *b* is therefore the place of burning hydrogen and the seat of illumination. The incandescent carbon particles, as they pass outward, meet with oxygen at *c*, and are converted into carbonic acid in the outer cone.

Fig. 216.



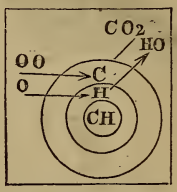

Shells of Flame.

**600.** To prove the constant presence of free carbon in the flame, it is only necessary to introduce into it any cold body, as a knife blade, or piece of porcelain, when it will be copiously deposited upon it as soot. Fig. 217 represents a cross section of the flame and the arrange-

candle. 598. What do Figs. 214 and 215 represent? 599. What is the order of

ment of its parts; CH the unburned carbon and hydrogen, H the sphere of burning hydrogen across which the carbon particles float, and lastly the sphere of burning carbon.

Fig. 217.



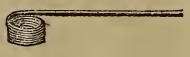

Cross Section of the Flame.

**601.** By noting any common flame, it will be observed that it burns blue, and yields but little light at the base. This is because the oxygen at this point is so abundant as to burn simultaneously both hydrogen and carbon. If we move a candle flame swiftly through the air, its light is diminished for the same reason. The conical form of the flame is due to the currents of heated air ascending around it.

**602.** The amount of light produced depends upon the intensity of the heat, as was before stated (399). Dr. Draper found that a body at 2,600° emitted almost 40 times as much light as at 1,900°.

**603. Effect of Cooling the Flame.**—If by any means the temperature of the flame falls below a certain limit it is immediately extinguished. The flame of a candle may be put out by lowering over it a coil of cold copper wire, Fig. 218. A piece of fine wire gauze held across the flame of a candle cools the combustible gases below the point of ignition, so that they rise through the meshes in the form of smoke, Fig. 219. The gauze may even become red hot and still not allow the flame to pass, so rapidly is the heat conducted away by the wire. Yet the cooled gases may be rekindled above, when the flame will go on burning as before, Fig. 220.

Fig. 218.



Copper Coil.

Fig. 219.

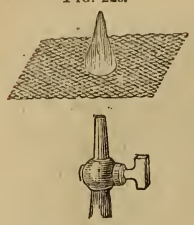
Gauze stops the Flame.

**604. Safety Lamp.**—On this principle the safety lamp is constructed. The explosions of carburetted hydrogen gas in coal mines from the unprotected lamps of the miners, caused immense destruction of life, and various arrangements had been fruitlessly contrived to prevent these

combustion? 600. How may the presence of free carbon in the flame be proved? Explain Fig. 217. 601. Why is there little light at the base? To what is the conical form due? 602. Upon what does the amount of light depend? 603. Explain Figs. 218 and 219. 604 What led to the invention of the safety lamp?

terrible accidents. At length Sir Humphry Davy took hold of the subject. He commenced a series of researches upon flame in August, 1815, and with such success as to produce the perfected lamp at the Royal Institution of London in the succeeding November. With large liberality he presented it to the public, unrestricted by a patent: and it is interesting to remember that the researches on flame to which we are indebted for the chief facts which have now been stated, were prompted by the noble desire of diminishing human suffering. As is frequently the case in all departments of investigation, so here; others besides Davy contrived safety lamps upon the same principle, unknown to each other.

Fig. 220.



Gas burns above.

**605.** They consist simply of ordinary oil lamps enclosed in a cage of wire gauze which permits the light to pass out, but prevents all exit of flame, Fig. 221. The space within the gauze often becomes filled with flame, from the burning of the mixed gases which penetrate the network; but the isolation is so complete that the explosive mixture without is not fired. Fatal explosions still occasionally take place, but they are due to carelessness of the miners. An explosion occurred not long ago killing nearly a hundred people, and it was subsequently traced to the fact that a miner had broken a hole into the gauze of his lamp to hang it upon a nail!

Fig. 221.

Safety Lamp.

**606. Influence of the Supply of Air.**—As the intensity of light depends upon the rapid consumption of oxygen, there must be a free supply of air, and provision for the ready escape of combustion products. The effect of a lack of air upon the flame may be seen by placing a glass cylinder over a burning candle so as to cut off the air; the flame becomes dingy and feeble, Fig. 222. By slipping a couple of blocks under the cylinder, Fig. 223, the combustion becomes more energetic than it would be in the open atmosphere, as by this means a rapid current of air is brought into con-

Give its history. 605. Of what does it consist? What is said of the effects of carelessness? 606. What experiments illustrate the influence of supply of air?

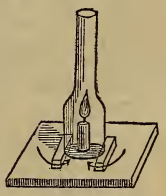
tact with the flame. If the cylinder be covered at top, the flame is extinguished by the accumulation of the products of combustion. On the other hand too much air is injurious, as so large a proportion of oxygen mingles with the combustible gases that the carbon and hydrogen burn together.

Fig. 222.

Air cut off.

**607. Argand Burner.**—This is an arrangement for increasing both the supply of air and the burning surface of the flame. In the candle flame and gas jet, combustion only takes place on the outside. The Argand burner has a circular wick by which a second current of air is admitted to the interior of the flame, thus burning with a double surface. This effect is increased by a glass chimney contracted so as to deflect the ascending outer current of air strongly upon the flame. See Fig. 224.

Fig. 223.



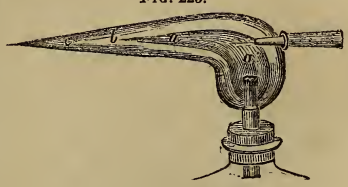
Air supplied.

**608. Blowpipe Flame.**—The high heat of the blowpipe flame is also due to the introduction of air into the centre of its flame. This is accomplished by blowing through a tube, the form of which and manner of using are seen in Fig. 226. On applying the blast the flame is deflected to the horizontal position, as shown more clearly in Fig. 225, and it now presents two distinct portions which have opposite chemical offices; *a a* represents the interior blue cone formed by the admixture of the oxygen with the unburned gases. The combustion is here complete and the heat of the flame most intense. From *b* to *c* is the luminous cone, which consists of unburned gases at a high temperature. These have a

Fig. 224.

Argand Burner.

Fig. 225.

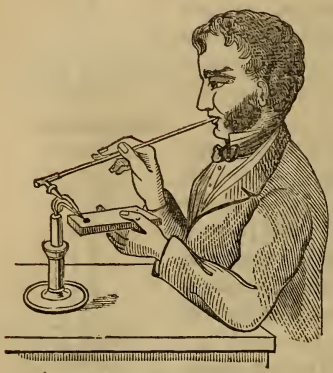


Blowpipe Flame.

607. What is an argand burner? 608. How does the blowpipe illustrate the same thing? What is the reducing flame of the blowpipe? The oxidizing flame?

powerful tendency to combine with oxygen and take it from the oxides of metals; it therefore forms a *reducing flame.* At the extreme point of the flame there is a reverse effect. There, oxygen at a high temperature is mechanically carried forward, and if driven against a metal rapidly oxidizes it; this point is therefore known as the *oxidizing flame.*

FIG. 226.



Using the Blowpipe.

**609.** It is interesting to note that the elements which have been chosen to form combustible bodies universally are the only ones adapted to the purpose. Their products, carbonic acid and watery vapor, are transparent and therefore do not cloud and eclipse the flame. They are also inodorous, tasteless, and, in small proportion, innocuous; while the oxides of all other combustible substances capable of existing in a gaseous state are pungent and irritating.

## CHAPTER X.

### THE HALOGENS, OR SALT FORMERS.

**610.** The bodies that compose this group are Chlorine, Bromine, Iodine, and Fluorine. They are characterized by their indifference to each other and their strong affinity for the metals, uniting with them to form a class of compounds of which chloride of sodium, or common salt is the type. Hence their name *Halogens*, or *salt producers.*

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609 What is said of the products of combustion? 610. What are the halogens? Why are they so named? 611. When and by whom was chlorine discovered? Where is it found? 612. How is it obtained? How is the reaction expressed?

# § I. *Chlorine and its Compounds.*

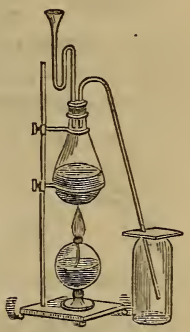
## CHLORINE.

*Sym. Cl. Equiv.* 35.5 *Sp. Gr.* 2.47.

**611.** Chlorine was discovered by SCHEELE in 1774, while noting the action of chlorohydric acid upon peroxide of manganese. It is never found free in nature, but exists abundantly in the mineral world, chiefly in combination with the metal sodium, as common salt. Animals and vegetables also contain it in this condition.

**612. Preparation.**—SCHEELE's method of obtaining chlorine by the action of chlorohydric acid on peroxide of manganese is still generally adopted. The manganese is placed in a flask provided with a safety tube for pouring in the acid, and a bent tube for conducting the gas to the receiver, Fig. 227. A little acid is first poured in and well shaken up with the manganese in order to wet every portion of it; more acid is then added and a gentle heat applied, when the gas is given off copiously. It may be collected over warm water or brine, and also by displacement, as seen in the figure. The greenish color of the gas from which it takes its name will indicate when the vessel is filled. The reaction may be thus expressed:

FIG. 227.



Making Chlorine.

$$MnO_2 + 2HCl = MnCl + 2HO + Cl.$$

Chlorine may also be prepared from common salt by the aid of sulphuric acid and oxide of manganese.

**613. Properties.**—Chlorine is one of the most energetic of the elements, surpassing even oxygen under some circumstances. Ordinarily it is a yellowish-green gas, but by a pressure equal to four atmospheres it may be condensed to a transparent, yellow liquid which remains unfrozen at —220°. The gas has a peculiar, suffocating odor, and if inhaled, even when considerably diluted, produces distressing irritation of the throat and lungs. When respired, however, in very minute quantities, it is not only harm-

613. What are the properties of chlorine? What does Fig. 228 illustrate? 614.

less, but is said to be beneficial to those affected with pulmonary disease. Chlorine maintains combustion; many bodies burn in it readily and some take fire in it spontaneously, such as phosphorus, finely powdered antimony, and arsenic. Many organic compounds, rich in hydrogen, are decomposed by it so rapidly as often to burst into flame. A piece of paper saturated with oil of turpentine and plunged into a vessel filled with chlorine, Fig. 228, emits a dense, black smoke and usually ignites, from the rapid decomposition of the turpentine. Chlorohydric acid is formed and carbon deposited.

Fig. 228.

Combustion in Chlorine.

**614.** Cold water absorbs about two and a half times its own bulk of chlorine, the solution acquiring the color, taste, and smell of the gas. If this solution is cooled down to 36° F., a definite crystalline hydrate of chlorine is formed, having the formula Cl + 10HO. Liquid chlorine may be readily obtained from these crystals by hermetically sealing them in a curved tube, Fig. 229, and applying a gentle heat. This liberates the chlorine, which, pressing upon itself, assumes the condition of a liquid. It may be distinguished from the water present by its yellow color. Chlorine solution readily dissolves gold, and also acts in some cases as a powerful oxidizing agent (608). Light decomposes chlorine water, giving rise to chlorohydric acid and free oxygen; hence it is necessary that it be kept in bottles protected by some opaque covering.

Fig. 229.

Condensing Chlorine.

**615. Bleaching Properties.**—One of the most valuable qualities of chlorine is its bleaching power. A solution of it in water, or the moist gas, immediately discharges the colors of ordinary fabrics, indigo, common ink, &c. It is principally used in bleaching cotton cloth and rags of which paper is to be made. We have seen that oxygen is a powerful bleaching agent (457), and in chlorine bleaching it doubtless takes an important part. Not only does chlorine destroy the coloring matter by uniting with its hydrogen, but in moist bleaching it decomposes the water, setting

How are chlorine crystals obtained? Liquid chlorine? Properties of chlorine

free oxygen which, in its nascent state, acts powerfully to oxidate and destroy the coloring particles. Dry chlorine will not bleach; it acts only through the agency of water. But it is so powerful that, if the bleaching solution is not quickly removed, it corrodes and weakens the fabric. It has no action upon carbon, and therefore does not bleach printer's ink. Nitrate of silver added to a solution containing chlorine, or a soluble chloride gives a white precipitate of chloride of silver, AgCl, which on exposure to light changes first to violet, and then to black. It is the universal test for chlorine.

**616. Allotropic Chlorine.**—This element, like oxygen, has its active and passive condition. When hydrogen and chlorine are produced and mingled *in the dark*, they do not unite; if exposed to diffused daylight, they gradually combine, and if to direct sunlight, they combine explosively. Dr. DRAPER found that chlorine gas which had been exposed to sunshine acquired the power of rapidly combining with hydrogen in the dark, and retained it for some time. When prepared in the dark, it is in a passive condition, but the effect of light so re-arranges its molecules as to exalt its activity and completely change its character. In its active state chlorine is highly electro-magnetic; in its passive state, it seems to become electro-positive, and capable of replacing hydrogen in combination (922). The more refrangible rays are chiefly instrumental in producing this change.

**617. Compounds of Chlorine.**—Owing to the active character of chlorine, it forms compounds with nearly all the elements. It unites directly with many of the metals, producing chlorides, and also forms several important combinations with the non-metallic elements. The metallic chlorides will be noticed under the metals;—we give here its more important non-metallic compounds.

**618. Chlorohydric Acid.** *HCl* (*Hydrochloric Acid*, *Muriatic Acid*).—The conditions under which these elements unite have just been noticed. The result is chlorohydric acid, a transparent, colorless gas, endowed with intensely acid properties. Two volumes of hydrogen combine with two of chlorine to form four volumes of the gas, no condensation taking place.

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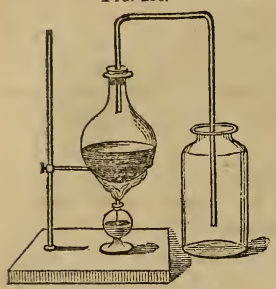
water? 615. How does chlorine act as a bleaching agent? 615. How does nitrate of silver act as a test for chlorine? 617. What are the chlorides? 618. How is hydrochloric acid formed? 619. What is Fig. 230? 620. What are the properties

**619. Preparation.**—For experimental purposes the gas may be readily obtained by heating a strong solution of chlorohydric acid in a glass flask furnished with a perforated cork through which a bent tube passes for conducting the gas to the receiver. Fig. 230 is a convenient arrangement for this purpose. The gas must be collected by displacement, as it is greedily absorbed by water.

Fig. 230.



Separating HCl.

**620. Properties.** — Chlorohydric acid gas is unrespirable, very irritating to the eyes, and not a supporter of combustion. It is somewhat heavier than air, having a specific gravity of 1.24. Under a presure of 40 atmospheres, it condenses into a colorless liquid which has never been frozen. When allowed to escape into the air, the gas combines with its moisture so rapidly as to produce white fumes. So great is its affinity for water that a lump of ice placed in a jar of the gas is liquefied, and the gas instantly absorbed. Free chlorohydric acid forms with ammonia dense white clouds of sal-ammoniac, as may be shown by bringing near each other two glasses, Fig. 231, one containing the acid and the other the alkali.

Fig. 231.

Gases producing a solid.

**621.** At a temperature of 40° F., water absorbs about 480 times its bulk of chlorohydric acid gas, increasing in volume about one third, and forming a colorless fuming, intensely acid liquid, having a specific gravity of about 1.247, known as muriatic acid, spirit of salt, &c. This solution is one of the most important requisites of the laboratory, and is also used for many purposes in the arts. The gas may be generated on a small scale by the action of dilute sulphuric acid on common salt aided by a gentle heat. Good proportions are two parts by weight of dilute acid to one part of salt. The gas is absorbed by cold water which is contained in a series of bottles connected with the generating flask, Fig. 232. The reaction consists in the de-

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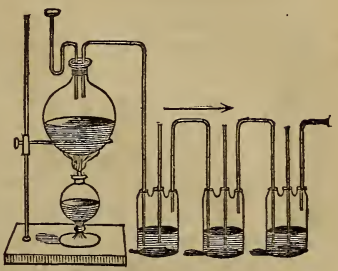
of H, Cl? Explain Fig. 231. 621. What is muriatic acid? Describe its preparation.

composition of the water of the sulphuric acid, its hydrogen taking the chlorine of the salt (which is composed of chlorine and sodium), and forming with it chlorohydric acid, while the oxygen unites with the sodium to form soda. The sulphuric acid combines with the soda, producing, if the acid is in excess, a bisulphate, while the gas escapes, and is taken up by the water in the bottles. Expressed in symbols we have

FIG. 232.



Preparing solution of HCl.

$$NaCl + 2\,HO, SO_3 = NaO, HO, 2SO_3 + HCl.$$

**622.** The condensation of chlorohydric acid gas is attended with the liberation of a large amount of heat, which raises the temperature of the water, thus reducing its capacity for absorbing the gas. To obviate this, the bottles are surrounded by ice, or a mixture of ice and salt. In the manufacture of the acid on a large scale, the decompositions are carried on in iron cylinders. The acid is condensed in stoneware vessels arranged like WOULFE'S bottles.

**623.** Chlorohydric acid gas occurs in large quantities as an incidental product in the manufacture of carbonate of soda from common salt. Until within a few years, the gas was allowed to escape into the atmosphere, where it condensed, and fell as a corrosive rain, to the great detriment of the surrounding vegetation. It is now condensed in large towers, built for the purpose, and connected with the furnace in which the *salt cake* or sulphate of soda is manufactured. Pure chlorohydric acid is colorless, but the commercial article has a yellow tinge due to organic impurities, free chlorine, iron, &c.

**624. Nitro-Chlorohydric Acid.**—A mixture of chlorohydric acid with nitric acid, constitutes the *aqua regia*, or royal water of the alchemists, so named from the power it possesses of dissolving gold, the 'King of metals.' The mixture acts by setting chlorine free, which, at the moment of its liberation, attacks the metals,

622. What precaution is necessary? 623. Where is it now made in large quanti-

dissolving and combining with them. The proportions for the mixtures are two measures of chlorohydric to one of nitric acid.

**625. Chlorine and Oxygen.**—The affinity of oxygen for chlorine is so feeble that the two elements can only be induced to unite by indirect means. The combinations are numerous, but we can only notice a few of the most interesting.

**626. Hypochlorous Acid,** ClO, may be obtained by passing dry chlorine through a tube filled with red oxide of mercury. A portion of the chlorine takes the place of the oxygen, forming chloride of mercury, while another portion unites with the oxygen, at the moment of its liberation, forming hypochlorous acid. As a gas, its color is a shade darker than that of chlorine, and it has a similar pungent odor. It is a powerful oxidizing agent, and possesses remarkably strong bleaching power.

**627. Bleaching Compounds.**—When chlorine is passed through recently slaked lime (hydrate of lime), large quantities of the gas are absorbed, forming the *bleaching powder* of commerce. A few chemists regard this and the similar compounds of potash and soda, as formed by the direct combination of chlorine with the base, having the formula in the case of lime CaO, Cl. The majority, however, maintain that they are compounds of hypochlorous acid with the base, which would make the symbol of the lime compound CaO, ClO. According to this view, the substances formerly known as chlorides of lime, potash, soda, &c., are hypochlorites of these bases.

**628. Hypochlorite of Lime,** CaO, ClO.—This is a white, sparingly soluble powder, used in great quantities for bleaching purposes. In the bleaching of cotton fabrics, the goods are first freed from all greasy impurities, and then digested in a solution of this powder. They are next dipped into very dilute sulphuric acid, where the chlorine is liberated, and exerts its bleaching power. This process requires to be repeated several times before the color is entirely discharged; after which the goods are thoroughly washed in water, in order to remove all trace of acid from the fibre of the cloth.

**629.** The change effected in modern days in the process of bleaching, is a striking example of the value of chemical skill as

ties? 624. What is said of aqua regia? 625. Of the compounds of chlorine and oxygen? 626. What is hypochlorous acid, and how is it obtained? 627. What are the theories of the composition of bleaching compounds? 628. How is the bleach-

applied to the industrial arts. Formerly, cotton and linen fabrics were bleached by steeping them in alkaline liquors, then boiling them in water, and exposing them for a long time upon the grass, where they were frequently sprinkled, and this was followed by soaking them for weeks in sour milk. This was repeated again and again, the process being not only slow and tedious, but requiring a large amount of manual labor, and a great extent of grass land. The substitution of dilute sulphuric acid for the sour milk, in dissolving out the alkaline matter, greatly reduced the time in this part of the process, while the subsequent application of chlorine still further shortened the operation, so that in two days is now accomplished what formerly took from four to eight months.

**630.** Chlorine is a disinfectant. It acts in the same way as in bleaching, by decomposing noxious effluvia. The chlorides of lime, potash, and soda are the compounds best adapted to this purpose, as they gradually evolve the gas at ordinary temperatures. *Chlorimetry* is the name given to the process by which the percentage of chlorine is determined in those compounds from which it may be obtained as a bleaching agent. The most accurate method, as devised by GAY-LUSSAC, consists in ascertaining the amount of arsenious acid which could be peroxidized by a known weight of the bleaching powder.

**631. Chloric Acid,** $ClO_5$.—This, the most interesting compound of chlorine and oxygen, has never been obtained in an uncombined form. It always retains one equivalent of water, $ClO_5HO$. If chlorine gas is passed through a strong solution of caustic potash, it is rapidly absorbed, and a bleaching liquid formed, which, on the application of heat, loses this property, and is converted into chloride of potassium and chlorate of potash. The chlorate of potash may be separated from the solution by crystallization, as it is less soluble than the chloride. Hydrofluo-silicic acid, added to a solution of these crystals, unites with the potash, carrying it down in an insoluble state, thus liberating the chloric acid, which may be obtained in a sirupy form, by evaporating the solution at a heat not exceeding 100°. A higher heat decomposes the acid. While in this state, it is very unstable, being de-

ing effected? 629. How is the change in the mode of bleaching spoken of? 630. How does chlorine act as a disinfectant? What compounds are best adapted for this, and why? What is chlorimetry? 631. How is chloric acid obtained?

composed by the presence of any combustible matter, and even by diffused daylight.

**632. Chlorates.**—The chlorates are characterized by the ease with which they yield their oxygen on the application of heat, by their powerful affinity for combustible substances, and by scintillating when thrown upon ignited coal. They are used as a source of oxygen, and in the manufacture of fireworks.

**633. Chlorous Acid, Peroxide of Chlorine, and Perchloric Acid** may be obtained by the decomposition of chloric acid. Sulphuric acid, poured upon chlorate of potash, liberates *chlorous acid* in the form of yellow vapors, which are very explosive. *Peroxide of chlorine* is also explosive. It resembles chlorous acid in appearance, and dissolves in about twenty times its bulk of water, forming a powerful bleaching solution. *Perchloric acid* is the most stable of the oxides of chlorine, and readily forms salts with various bases, which are all soluble, and decomposable by heat.

## § II. *Bromine, Iodine, Fluorine.*

### BROMINE.

*Sym. Br. Equiv.* 80. *Sp. Gr. at* 32°, 3.187.

**634. Bromine** was discovered by BALLARD, a French chemist, in 1826, in the 'mother liquor,' or *bittern*, left after the extraction of the crystallizible salts from sea water. This is the principal source of the element, although it is found in the waters of various saline springs, and in a few minerals. Bromine is prepared by introducing into the mother liquor a current of chlorine, which sets it free. Ether is then added, which, on agitation, takes up the bromine, and rises to the surface as a deep red stratum.

**635. Properties.**—Bromine is the only element, except mercury, which exists as a liquid at ordinary temperatures. It is of a deep red color, and very volatile, with a disagreeable, irritating odor, from which its name is derived. It is a powerful poison, a drop on the beak of a bird producing instant death. It has bleaching

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632. Describe the chlorates. 633. What is said of chlorous acid? Peroxide of chlorine? Perchloric acid? 634. Where is bromine found? How is it prepared? 635. Properties of bromine? Uses? 636. What are the sources of iodine? Its

properties, and is soluble in water. It is used in photography, and, in minute quantities, as a medicine. Like chlorine, it forms an acid with hydrogen, and also unites with oxygen, giving rise to bromic acid, the only known compound of these two elements.

## IODINE.

*Symb. I. Equiv.* 126.8. *Sp. Gr.* 4.94.

**636.** This useful substance was discovered by M. Courtois, of Paris, in 1811. He first observed it in kelp, or the ashes of sea-weed, and it is still obtained from this source for commercial purposes. It exists in mineral springs, and has also been found in minute quantity in certain minerals. In its preparation the ashes are leached, and the solution evaporated, until the more readily crytallizable salts are removed. The mother liquor, which contains the iodine as iodide of sodium, is then distilled with sulphuric acid and oxide of manganese, when the iodine comes over as vapor, and is deposited in the form of brilliant, bluish-black scales, resembling plumbago in appearance.

**637. Properties.**—Iodine is a non-conductor of electricity, and is sparingly soluble in water, though easily dissolved by ether or alcohol. When heated, it rises as a beautiful purple vapor; hence its name, from *iodes*, violet-colored. In various forms, it is used extensively in medicine, but, taken in large doses, it acts as an irritant poison. The test for iodine is moistened starch, with which it forms a deep blue compound. If the iodine is in combination, it may be liberated by the addition of a little chlorine water, as it is necessary to the success of the test that it be in the *free state.* One part of iodine in a million of water may be detected by this means.

**638. Iodohydric Acid,** HI, may be obtained in the form of a gas by heating iodine in hydrogen. It is a strong acid with a pungent odor, very soluble in water, and readily decomposed by chlorine or bromine. Iodine combines with the metals, forming compounds remarkable for the beauty and variety of their colors. Its most important compound is formed by its union with potassium, which gives KI, or iodide of potassium. Like chlorine and

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preparation? 637. What are its properties? What its uses? What is its test? 638. What are the properties of iodohydric acid? Other compounds of iodine?

bromine, it unites with oxygen, but the compounds possess no general interest.

## FLUORINE.

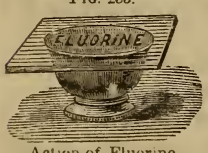
*Sym. F. Equiv.* 19. *Sp. Gr.* 1.31.

**639. Fluorine** is only known in combination. It exists in various minerals, but most abundantly in fluorspar (fluoride of calcium), from which it is obtained as fluohydric acid by means of sulphuric acid. It is also found in minute quantity in the bones of animals and the enamel of the teeth, to which structures it is supposed to give hardness. Fluorine forms compounds with all the metals, and with many of the non-metallic elements, but it cannot be induced to unite with oxygen.

**640. Fluohydric Acid,** HF (*Hydrofluoric Acid*).—This may be obtained by decomposing fluorspar with sulphuric acid, the operation being usually aided by a gentle heat. Owing to the powerfully corrosive quality of this acid, it is prepared in leaden vessels. If required perfectly pure, platinum or silver vessels are used. The acid, as thus obtained, is a fuming, white liquid, which requires the greatest care in dealing with it, as, if allowed to come in contact with the skin, it produces a deep and exceedingly painful sore, very difficult to heal. It combines with water with avidity, producing a hissing noise. Many of the metals dissolve in it, fluorides being formed, and hydrogen liberated. Potassium decomposes it with an explosion.

**641.** The distinguishing characteristic of fluohydric acid is its corrosive action on glass. This may be shown by placing some powdered fluorspar, made into a paste with sulphuric acid, in a leaden cup, Fig. 233, and covering it with a plate of glass, previously smeared on one side with beeswax, through which characters have been traced with a fine-pointed instrument. The waxed side is placed next the mixture, and a gentle heat applied to the cup. After the lapse of half an hour, on removing the glass, and cleaning off the wax with the aid of a little oil of turpentine, the characters will be found eaten

Fig. 233.




Action of Fluorine.

639. What is said of fluorine? 640. How is fluohydric acid prepared? What are its properties? 641. Explain the process of etching upon glass. 642. What is the

into the glass. The acid has combined with the silica of the glass at the exposed points. This quality is taken advantage of to etch the labels on glass bottles that are to be used in laboratories and drug shops, where corrosive substances abound.

# CHAPTER XI.

## THE PYROGENS OR FIRE PRODUCERS.

## § I *Sulphur and its Compounds.*

**642.** The elements of this group, Sulphur, Selenium, Tellurium, and Phosphorus, are closely allied to each other and marked by their strong attraction for oxygen.

### SULPHUR.

*Sym. S. Equiv.* 16. *Sp. Gr.* 2.

**643. Sulphur** is a brittle yellow, solid, highly inflammable, burning with a bright blue flame, and is insoluble in water or alcohol, but soluble in bisulphide of carbon. It is a non-conductor of electricity, and but a poor conductor of heat.

**644. Sources.**—Sulphur exists abundantly in nature, both free and in combination. It is found native in various volcanic districts, especially in the island of Sicily, where it is mined in immense quantity for the market. Many springs and small lakes, in which it is evolved in the combined gaseous state, often deposit it in considerable quantities. It exists in combination with various metals, forming sulphides, and, as a constituent of sulphuric acid, it is found in gypsum and other minerals.

**645.** Sulphur exists in plants, entering their roots in some soluble combination, and is present in a free state in the bodies of animals, chiefly in their muscular parts. It exists in eggs, and discolors the silver spoons with which they are eaten by forming the black sulphide of silver. The efficiency of many preparations for staining the hair black depends upon the lead they contain, which unites with the sulphur of the hair.

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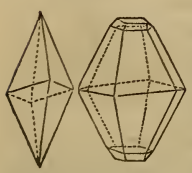
distinctive property of this group? 643. What are the properties of sulphur? 644. What are its sources? 645. Where else does it exist? 646. How is it purified?

**646.** Sulphur is volatile, and sublimes by heat. Advantage is taken of this property to separate it from the mineral impurities with which it is found associated. It undergoes a rough distillation in earthen retorts. Iron pyrites contains 50 per cent. of sulphur, which is separated either by roasting it in large heaps in the air, and collecting the melted sulphur in cavities, or by heating the pyrites in tubes, and running off the sulphur into vessels of water.

**647. Its Forms.**—In commerce, sulphur exists in forms due to the different modes of its preparation: 1st, as *flour of sulphur*, a pale, yellow, gritty powder, obtained by sublimation; 2d, as *milk of sulphur*, where it is procured in a very minute state of subdivision, by dissolving sulphur in a solution of an alkali, and precipitating it with an acid; 3d, *roll sulphur*, or brimstone, obtained by running it into moulds in the melted state.

**648. Its Allotropic States.**—These are three. First, crystals which take the form of right, rhombic octahedrons, Fig. 234. They occur in nature, and may be produced by evaporating a solution of sulphur in bisulphide of carbon. These crystals have a sp. gr. of 2.05, and undergo no change in the air. The second form is that of oblique, prismatic crystals, which may be obtained by melting ordinary sulphur in a crucible, and after it has cooled breaking the vessel, when the still fluid portion flows out, leaving a mass of crystals attached to the inner surface of the crucible, Fig. 235. These have a sp. gr. of 1.98, are not permanent in the air, and require a higher temperature to melt them than the former.

FIG. 234.



Sulphur Crystals

FIG. 235.

Crystals by Fusion.

**649.** The third allotropic condition is obtained by the action of heat. Sulphur melts at 239° into a thin, pale, yellow liquid, in which solid sulphur sinks. If the heat is raised to 480°, it changes into a thick, tenacious, molasses, colored body, which, if poured into cold water, becomes soft and elastic, like India rubber. In this state it

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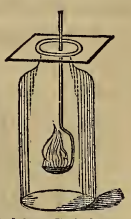
How obtained from pyrites? 647. What is flour of sulphur? What is milk of sulphur? What is roll sulphur? 648. What is the first allotropic form of sulphur?

is used to take impressions of medals, coins, &c.; but it gradually resumes its former brittle condition. Sulphur is consumed largely in the manufacture of gunpowder, friction matches, sulphuric acid, and in medicine. It has an extensive range of affinity, ranking next to oxygen in this respect, and forming many important compounds.

**650. Sulphurous Acid, $SO_2$.**—When sulphur is ignited in the air, or in pure oxygen, Fig. 236, it burns with a beautiful blue flame, and forms sulphurous acid. This is a transparent, colorless gas, having a pungent suffocating odor familiarly known in the case of a burning match. It extinguishes combustion; hence sulphur is often thrown into the fire to quench the burning soot of chimneys. It has a strong attraction for water. Allowed to escape into the air, it forms white fumes with its moisture, and a piece of ice thrust into the gas is instantly liquefied. Water at 60° takes up large quantities of this acid, the solution formed having the taste and smell of the gas. By cold or pressure it condenses into a liquid, and evaporates so fast that the cold generated will freeze water even in a red-hot crucible.

FIG. 236.



Making Sulphurous Acid.

**651.** Sulphurous acid is used as a disinfectant, and in bleaching woollen and straw fabrics. The goods are moistened, and suspended in large chambers, or, in a small way, they are put in inverted barrels, and exposed to the fumes of burning sulphur. The effect is produced, not by destroying the coloring matter, as in the case of chlorine, but by the union of the acid *with* the coloring matter, which forms a white compound. If a red rose is held over burning sulphur, it is whitened, but the color is at once restored by weak sulphuric acid, which, being stronger, discharges sulphurous acid from combination. If woollens, after sulphur bleaching, are washed with a strong alkaline soap, the acid is neutralized by the alkali, the coloring matter liberated, and the yellowish color restored.

**652.** Sulphurous acid may be conveniently prepared by heating strong sulphuric acid with copper turnings. One equivalent of the acid parts with one equivalent of its oxygen, thus liberat-

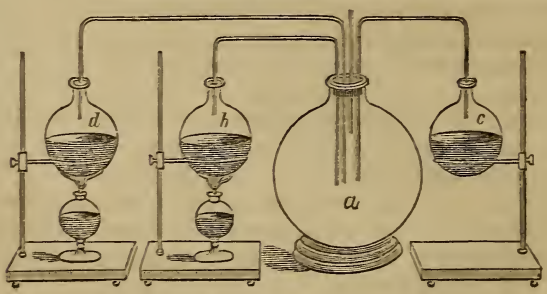
The second? 649. The third? For what is it used? 650. How is sulphurous acid formed? What are its properties? 651. For what is it used? How does it act in

ing the sulphurous acid gas, while the oxide formed unites with another proportion of the acid, producing sulphate of copper.

**653. Sulphuric Acid,** $So_2HO$.—This powerful acid is of great interest to chemists and manufacturers. It is found native in the craters of many volcanoes, and in the water of mineral springs. It was formerly prepared by distilling dry sulphate of iron (green vitriol); hence its old name, *oil of vitriol.* Now, however, it is usually obtained by combining one equivalent of oxygen with sulphurous acid. $SO_2$ is thus converted into $SO_3$.

**654.** Sulphuric acid may be prepared on a small scale by an

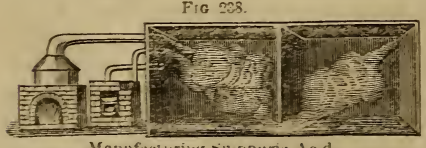
Fig. 237.




Arrangement for Preparing Sulphuric Acid.

apparatus represented by Fig. 237. A large glass balloon, *a*, is connected by tubes with three flasks. Flask *b* supplies it with sulphurous acid; *c*, with deutoxide of nitrogen; *d*, with steam, and the short tube furnishes air. These four substances react upon each other with the continued production of sulphuric acid. In the manufactory the balloon is represented by large chambers lined with sheet lead, and the flasks by furnaces, Fig. 238. In one furnace sulphur is heated, and pours into the chamber sulphurous acid, $SO_2$. In another, nitre is heated in an iron pot with sulphuric acid,

Fig 238.

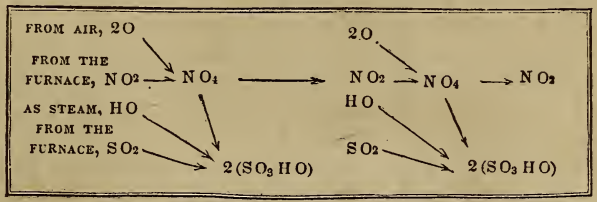


Manufacturing Sulphuric Acid.

bleaching? What restores the color? 652. How may $SO_2$ be prepared? 653. What is sulphuric acid? What gave it its old name? 654. Describe the process

by which fumes of nitre acid, $NO_5$, are produced and delivered into the chamber. The $NO_5$ is quickly deprived of an atom of oxygen by the sulphur, and becomes $NO_4$. Steam and air are thrown into the chamber by another flue, and thus the conditions of action are secured.

**655.** The process depends upon the property possessed by the higher oxides of nitrogen of oxidizing sulphurous acid at the expense of the oxygen of the atmosphere. The sulphurous acid is converted into the sulphuric, the oxygen being derived from the air, and the deutoxide of nitrogen being the carrier that transports it. A small quantity of $NO_2$ may thus form an endless quantity of $SO_3$. These changes are represented in the following scheme.




**656.** The large chambers of the manufactory are divided by leaden partitions with narrow openings, which serve to facilitate the intermixture of the gases as they pass on through the apartments. The bottom of the chamber is always kept covered with water to the depth of two or three inches, to absorb the acid as it falls. When the water has acquired a density of 1.5, by the absorption of acid, it is drawn off and boiled down in glass or platinum retorts, until it has a specific gravity of about 1.8. The acid thus obtained contains one equivalent of water to one of acid, $SO_3HO$, and constitutes the ordinary sulphuric acid of commerce.

**657. Properties.**—Sulphuric acid has a thick, oily appearance, is without odor, and has at first a soapy feel, but it speedily corrodes the skin, causing an intense burning sensation. It is the most powerful of acids, and has an intense affinity for water. When a splinter of wood is dipped into it for a short time, it turns black, the acid taking away from it the elements of water, and leaving the carbon. In like manner, it decomposes and chars the

of its preparation? 655 Upon what does the action depend? How is it effected? 656. What further occurs in the manufactory? 657. What are the properties of sulphuric acid. What is said of its affinity for moisture? What effects accom-

skin and most other organic substances by removing their water. If a little concentrated acid is exposed to the open air in a shallow dish it will soon double its weight from the moisture absorbed. When sulphuric acid and water are mixed they shrink in bulk, and heat is produced. A mixture of four parts concentrated acid to one part water, Fig. 239, evolves sufficient heat to boil the ether in a test tube. The concentrated acid freezes at about −30°, and boils at 640°. Pure sulphuric acid is colorless, but slight traces of organic matter, as dust or straws, turn it of the dark shade usually seen in commerce. The commercial acid is cheap, but impure, containing traces of lead, arsenic, potash, and chlorohydric and sulphurous acids.

Fig. 239.

Boiling Ether.

**658.** Sulphuric acid is extensively used in the manufacture of carbonate of soda and chlorine, of citric, tartaric, acetic, nitric, and hydrochloric acids, of sulphate of soda, sulphate of magnesia, and various paints, also in dyeing, calico printing, gold and silver refining, and in purifying oil and tallow. Its chemical uses are innumerable. The test for sulphuric acid is chloride of barium, with which it forms a white insoluble salt.

**659. Nordhausen Sulphuric Acid.**—This is manufactured by the original process—the distillation of dried sulphate of iron in earthen retorts. It is a dihydrate, having one equivalent of water to two of acid, $2SO_3+HO$, and is the strongest variety of sulphuric acid. It derives its name from being manufactured in the town of Nordhausen, in Saxony.

**660. Sulphuric Anhydride,** $SO_3$.—This may be obtained in the form of a white snowy solid, by distilling the Nordhausen acid, and collecting the fumes which pass over in a receiver surrounded by a freezing mixture. While in this condition, it exhibits no acid properties, and may be handled with impunity, if the hands are dry. But it fumes in the air, and rapidly absorbs moisture. When thrown into water it hisses like a hot iron, and the solution thus formed possesses all the properties of the ordinary acid.

**661. Hydrosulphuric Acid,** HS (*Sulphydric Acid*, *Sulphuretted Hydrogen*, *Sulphide of Hydrogen*).—This is a colorless, transparent gas, having the well-known odor of decayed eggs. It is feebly

pany their union? What is said of the commercial acid? 658. For what is it used? What is its test? 659. What is the Nordhausen acid? 660. How is the anhydride obtained? What are its properties? 661. Give the composition of sul-

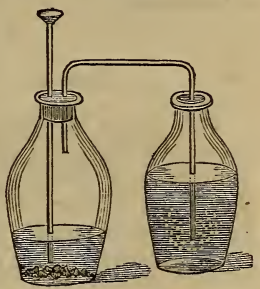
acid, and burns with a pale blue flame, producing sulphurous acid and water. When breathed it is highly poisonous, and even when much diluted with air it has been proved fatal to many of the lower animals. By pressure the gas may be condensed to a colorless, limpid liquid, which freezes at −122°, the frozen portion sinking in the liquid. It readily dissolves in water, imparting to the solution its own taste and smell, as well as its slightly acid properties. This gas is an abundant natural product from sulphur springs and the decay of organic matter containing sulphur, as albumen of eggs, flesh, &c.

**662. Preparation.**—It is usually obtained by decomposing protosulphide of iron with dilute sulphuric acid,

$$FeS + SO_3, HO = FeO, SO_3 + HS.$$

Fig. 240 represents a convenient arrangement for its evolution. The sulphide of iron should be broken into small lumps and placed in the flask. The cork and tubes may then be adjusted, and first water and then sulphuric acid poured in through the funnel tube. The gas is absorbed by the water of the second vessel. The solution must be kept in tightly secured bottles, as, if exposed to the air, it is gradually decomposed. Hydrosulphuric acid is one of the most important chemical reagents, and is used for precipitation of the metals.

FIG. 240.



Preparing Sulphuretted Hydrogen.

**663. Bisulphide of Carbon,** $CS_2$ (*Sp. Gr. of Liquid*, 1.272; *of Vapor*, 2.644).—This is a very volatile, colorless liquid, boiling at 118.5°, has a sulpurous odor and pungent taste. It has never been frozen, and is used in thermometers which are to measure very intense degrees of cold. It is highly inflammable, burning with a blue flame, and yielding carbonic and sulphuric acids. It dissolves sulphur, phosphorus, and iodine, and is dissolved in ether, but not in water. It is produced by bringing vapor of sulphur into contact with red-hot charcoal, the compound vapor being condensed

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phuretted hydrogen. What are its properties? 662. How is it prepared? Explain Fig. 240. For what is it used? 663 What is bisulphide of carbon? State

in cold vessels. From its high dispersive power over light, it is used to fill hollow prisms of glass for spectroscopic observations.

## § II. *Selenium and Tellurium.*

### SELENIUM.

*Sym. Se. Equiv.* 39.7. *Sp. Gr.* 4.8.

**664.** This is an element of rare occurrence. It has not been found free, but usually occurs in combination with iron, copper, or silver. It is a brown, brittle solid, of metallic lustre and a glassy fracture. It presents a strong resemblance to sulphur, uniting with oxygen to form acids corresponding to the sulphurous and sulphuric, and with hydrogen to form the selenide of hydrogen, a compound, if possible, more offensive than sulphide of hydrogen.

### TELLURIUM.

*Sym. Te. Equiv.* 64.5. *Sp. Gr.* 6.6.

**665.** A rare substance, found sometimes native, but generally combined with metals. It has a metallic aspect resembling bismuth, and was formerlly classed with the metals, but it is now placed with sulphur and selenium on account of its strong analogy with these bodies. Its compounds with oxygen and hydrogen resemble those of its associates.

## § III. *Phosphorus and its Compounds.*

### PHOSPHORUS.

*Sym. P. Equiv.* 31. *Sp. Gr.* 1.83.

**666.** This interesting body is a soft, colorless, half-transparent, waxy solid, so extremely inflammable that it takes fire in the open air by the heat of the slightest friction, and burns with great violence, emitting a brilliant flame, and dense, white fumes of phosphoric acid. If quietly exposed to the air it undergoes slow oxidation, emitting white vapors of an odor like garlic. It must be

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it properties. Uses. 664. What is selenium? 665. What is tellurium? 666. What are the properties of phosphorus? Why is it kept under water? What are its

handled with caution, as the burns it produces are deep and difficult to heal. From its inflammability it is kept under water. It is insoluble in water; partially soluble in ether, but dissolves readily in bisulphide of carbon and various oils.

**667. Source and Preparation.**—Phosphorus combines with oxygen, forming phosphoric acid, and then unites with lime, producing phosphate of lime. In this form phosphorus exists in bones, the phosphate of lime forming the mineral portion. The skeleton of a man contains from $1\frac{1}{2}$ to 2 lbs. of phosphorus. To obtain it, the bones are first burned, and, the organic matter being consumed, they are reduced to powder and soaked in concentrated sulphuric acid. This decomposes the phosphate, removing two thirds of the lime. The remainder is then heated to a high temperature with charcoal in a close vessel. The carbon unites with the oxygen, liberating the phosphorus, which rises in vapor, and is condensed in water in the shape of yellow drops. These are melted under water and forced into tubes, thus forming the ordinary stick phosphorus.

**668. Discovery.**—Phosphorus was discovered by BRANDT in 1669. The name signifies *bearer of light*, and was given on account of its property of being luminous in the dark. In all its characteristics, it was a very extraordinary body. 'If touched it took fire and burned furiously, exhaling a dense white cloud, which gathered like fleeces of snow, but, unlike snow, hissing like a red-hot iron when touched with water or, if brought into contact with the body, blistering it like living fire.' We may imagine the mingled wonder and dread of the devout alchemists as they passed precious little bits of it around among the initiated under a name which hinted their dark suspicions—'the Son of Satan.'

**669. Phosphorescence.**—If solutions of phosphorus in ether be spread upon the face in the dark, it causes a pallid glow, which soon passes away. The cause of this self-shining of phosphorus is probably its slow oxidation. BERZELIUS stated that it became luminous in nitrogen, hydrogen, or even in a vacuum, but SCHRÖTTER's more careful experiments show that to produce the effect a little oxygen must always be present.

**670. Its Allotropic Forms.**—Among the marked properties

solvents? 667. What is its source? How is it obtained? 668. How was it at first regarded? 669. How may phosphorescence be exhibited? To what is it due?

of this singular substance is the diversity of its allotropic conditions. It assumes six different forms. The *first* is the common transparent state, or vitreous phosphorus. When this is exposed to light under water it changes to the *second* variety, which is white, opaque, and less fusible. The *third* is a symmetrical crystal of the regular system, formed by evaporating some of its solutions. The *fourth* is a black, opaque variety, produced by sudden cooling of the melted phosphorus; *fifth*, a soft elastic substance analogous to viscous sulphur, and formed by suddenly cooling phosphorus when near its boiling point; and, *sixth*, a red amorphous sort, which may be obtained by exposing vitreous phosphorus to the rays of the sun between two plates of glass.

**671.** This red amorphous variety may also be produced by heating common phosphorus in an atmosphere of carbonic acid, when it is obtained as a brick-red powder. As vitreous phosphorus may be called the active variety, this is the opposite or passive form. It is heavier than the former, red in color, does not shine in the dark, nor melt at the heat of boiling water. It exhales no vapor or odor; oxidizes but very slowly in the air, does not change oxygen into ozone, is chemically indifferent toward other elements, may be handled with impunity, or carried exposed in the pocket, and is not poisonous when administered in doses a hundred times greater than would be fatal in the common form (G. Wilson). At 500° it is reconverted into the active form and bursts into flame.

**672. Uses.**—The chief use of phosphorus is in the manufacture of friction matches, and vast quantities are consumed in this way among all civilized nations. In making matches the blocks are sawn by machinery, and the ends first tipped with sulphur, and then with an emulsion of phosphorus in glue, with a little saltpetre, oxide of manganese, or chlorate of potash; bodies all rich in oxygen. The manufacture is not only dangerous from the explosive nature of the materials used, but from the corrosive phosphoric vapors, which produce among the laborers the distressing disease known as caries of the lower jaw. An attempt has been made to avoid these evils by the use of passive phosphorus in this manufacture, but as yet with only partial success.

**673. Office in Nature.**—The part played by phosphorus in the scheme of nature is of the highest interest. Existing, combined

670. How many are its allotropic forms? What are they? 671. What are the properties of passive phosphorus? 672. For what is phosphorus used? Describe

with lime, in the primitive and volcanic rocks, by their gradual decay in the course of ages, it passes into the soil. The plants, with their thousand rootlets sucking up the soluble extract of soil, obtain compounds of phosphorus, which rise with the sap to the leaf. It is maintained by some that a portion of its compounds is here decomposed, the phosphorus being set free and thrown into the passive state by the chemical influence of the sunbeam (372). However this may be, it is stored up in the seeds which are destined to nourish man and the higher animals. One portion is employed to build up the bony structure, while another forms a large constituent of the nervous system and brain. What the precise office of phosphorus in the brain may be we cannot say, but that it performs some high duty in the reactions of the mind with its organ, is manifest from the fact that after prolonged brain-exercise there is a rise in the proportion of phosphoric products in the liquid excretion.

**674.—Phosphoric Acid,** $PO_5$ (*Phosphoric Anhydride*).—When phosphorus is burned in dry oxygen, Fig. 241, the dense, white vapors which are formed condense upon the glass in snow-like flakes. This is *phosphoric anhydride.* It has a powerful attraction for moisture, absorbing it from the air, or, if brought into contact with water, seizing it with such violence as to emit a hissing sound. Phosphoric acid is thus formed, which always contains water in its composition. By evaporation, a vitreous-looking substance is produced, known as *glacial* phosphoric acid. Its solution is very sour.

FIG. 241.

Combustion of Phosphorus.

**675.** The intensity of the attraction of phosphorus for oxygen may be strikingly shown by directing a stream of the gas against a small piece of phosphorus at the bottom of a vessel of warm water, when a brilliant combustion will be observed beneath the liquid, Fig. 242.

FIG. 242.

Under Water.

**676.** Phosphoric acid is procurable from bones by the action of sulphuric acid, which displaces it by seizing the lime, or by the direct oxidation of phosphorus

the process. What is said of its dangers? 673. Whence do plants obtain their phosphorus? What are its offices in the animal system? Its relations to mental action? 674. What is phosphoric anhydride? Glacial phosphorus? 675. How is

by nitric acid. It combines with water in three proportions, forming

Monobasic or metaphosphoric acid, HO, $PO_5$.
Bibasic or pyrophosphoric acid, 2HO, $PO_5$.
Tribasic or common phosphoric acid, 3HO, $PO_5$.

These three acids give rise to three series of salts.

**677. Phosphide of Hydrogen,** $PH_3$ (*Phosphuretted Hydrogen*).—This is a colorless gas, with a very offensive odor, is poisonous when inhaled, and produced in small quantities by the decay of animal matter. It may be prepared by heating small fragments of phosphorus with a strong solution of caustic potash in a retort. The end of the retort tube dips beneath water, and as the gas passes out in bubbles, it rises to the surface and takes fire spontaneously. If some pieces of the phosphide of calcium are thrown into a glass of water, the same thing takes place. Double decomposition with the water produces phosphuretted hydrogen, which ignites at the surface and forms beautiful wreaths of vapor, Fig. 243. The other phosphides of hydrogen are of little interest.

Fig. 243.

Wreaths of Flame.

**678.** Phosphorus combines with chlorine so energetically as to take fire. It also forms numerous compounds with iodine, bromine, nitrogen, and sulphur, but they are comparatively unimportant.

## CHAPTER XII.

### THE HYALOGENS OR GLASS FORMERS.

### § I. *Silicon and its Compounds.*

#### SILICON.

*Sym. Si. Equiv.* 14.

**679. Silicon.**—This element is never found free in nature, but exists very extensively in the mineral crust of the earth in

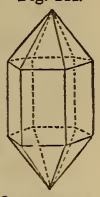
its intense attraction for water shown? 676. How is it obtained from bones? Whence arise the three series of salts? 677. What are the properties of phosphu-

combination with oxygen, forming silica. It has three allotropic states: first, amorphous silicon—a brown powder; second, a variety resembling graphite; and third, a crystalline form. It holds an equivocal place in classification, some ranking it with the metals. It is difficult to separate, and is of no importance except to the scientific chemist.

**680.—Silica,** $SiO_2$ (*Silicic Acid*, *Silex*, *Sand*).—This is a compound of silicon and oxygen, the proportions of which are unsettled. Berzelius held that it is $SiO_3$, analagous to sulphuric acid, and this view has been generally accepted. But later chemists consider it as $SiO_2$, or analogous to carbonic acid.

**681.—Silica** is the most abundant of mineral substances. Its purest condition is that of quartz, in which it forms hexagonal crystals terminated by six-sided summits, Fig. 244. If this mineral is heated to redness and quenched in water, it is reduced to a fine, white, tasteless, gritty powder, which is nearly pure silica. The chief constituents of all sandstones is silica, and it occurs in large proportion in many other rocks; these, by decomposition, yield the silicous principle or sand of soils. The common flint and many valuable stones, as amethyst, agate, chalcedony, carnelian, jasper, opal, and sardonyx, consist of silica, variously colored by other substances.

Fig. 244.



Quartz Crystal.

**682. Solubility.**—In pure water, and in all acids, except the hydrofluoric, it is insoluble, but it is dissolved by alkaline solutions. Hence, all natural waters which contain alkaline carbonates hold also in solution a little silica. If wood be present in such waters, as it decays, the particles of silica are deposited in place of those that escape, and thus a copy of the wood in stone, or a *petrifaction*, is produced.

**683. It is an Acid.**—Though so insoluble and inert, silica is really an acid, combining with bases, and forming silicates which are true salts. By the intense heat of the oxyhydrogen flame it is melted into a pure glass, and may be spun out into threads. But when mixed with alkalies it melts at a lower temperature, combining with them to form ordinary glass. The most abundant min-

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retted hydrogen? How is it obtained? 678. Other compounds of phosphorus? 679. Where is silicon found? What are its allotropic forms? 680. What is the composition of silica? 681. What is the purest silica? What is said of its abundance? 682. Its solubility? How are petrifactions formed? 683. What are sili-

erals, mica, feldspar, hornblende, serpentine, &c., which form the granitic, and many other rocks, are silicates of the alkalies and alkaline earths;—like glass, they are also salts.

**684. Silica of Soil.**—At common temperatures carbonic acid is stronger than silicic; hence, upon many of the silicates the air exerts a destructive agency. Its carbonic acid slowly unites with their bases, setting the silica free, thus forming one of the disintegrating forces by which rocks are reduced to the condition of soil. At the moment of its liberation it is soluble in water. In this way, but still more powerfully by the action of alkalies, silica is dissolved by the water of soils, and, entering the roots of plants, performs an important office in giving stiffness and strength to the stalks of grains and grasses.

**685. Soluble Glass.**—If 8 or 10 parts of carbonate of soda or potash are mixed with 12 or 15 parts of sand and 1 of charcoal, on being heated they melt, and form a mass resembling ordinary glass; but it entirely dissolves in hot water. This is known as *soluble glass*, and when applied to wood and other substances answers the protective purpose of a varnish or paint.

**686. Its Colloidal Form.**—If to a solution of soluble glass, chlorohydric acid be added, it neutralizes the alkali, and the silica separates as a transparent jelly—a fine example of the *colloid* state (83). It is a hydrate of silica, and is insoluble in water or acids. This gelatinous state may be continued by keeping it moist, but as soon as it is deprived of water it falls to a gritty powder.

**687. Fluoride of Silicon,** $SiF_2$ (*Fluosilicic Acid*).—This is a colorless gas produced when fluohydric acid is liberated in contact with silica. When passed into water the gas is decomposed, the silica becoming gelatinous, and the water a solution of hydrofluosilicic acid, $HF, SiF_2$.

**688. Silicates** are salts of silica, and form a large class of natural minerals. Most of them are fusible; some, however, melt at only very high temperatures. They are all insoluble in water except the silicates of the alkalies. Those artificial silicates which are of interest in the arts will be noticed when speaking of their respective bases.

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cates? Give examples. 684. What is the action of carbonic acid upon silicates? What is the office of silica in plants? 685. What is soluble glass? 686. Describe its colloidal form. What is it? 687. What is fluoride of silicon? 688. State the

## § II. *Bóron.*

*Sym. B. Equiv.* 10.9.

**689. Boron** is a rare substance always found in combination with oxygen, as boracic acid. It strongly resembles silicon, and, like it, is capable of assuming three allotropic states.

**690. Boracic Acid,** $BO_3$.—This is found as a natural constituent of several minerals, but the principal supply is derived from the lagoons of Tuscany. Here, the acid issues from the earth along with jets of steam, and is collected by throwing the jets into water. The acid is afterward separated from the water by evaporation in leaden pans so arranged that they are heated by the vapors as they escape from the earth. It is deposited in white, scaly crystals, which are purified by repeated crystallizations. These crystals have a glassy appearance, and are soapy to the touch. They dissolve much more readily in boiling than in cold water, and form a solution having feebly acid properties.

# CHAPTER XIII.

## THE METALLIC ELEMENTS.

## § I. *General Properties of the Metals.*

**691.** The metals form the largest division of the chemical elements, and are distinguished by certain characteristics which they manifest in very different degrees. They have all a peculiar shining appearance, called the *metallic lustre.* Most metals, however, may be obtained in conditions free from this lustre, while some bodies which are not metals, as iodine and plumbago, have also a metallic brightness. They vary in color; several, as silver and platinum, are white, with tints peculiar to each; others, as lead and tin, are bluish; iron and arsenic are grayish; calcium and barium a pale yellow; gold a bright yellow, and copper red.

**692. Hardness, Brittleness, Tenacity.**—In hardness the metals exhibit wide differences; steel scratches glass, while potassium is

properties of the silicates. 689. What is boron? 690. How is boracic acid obtained? 691. How are the metals distinguished? What of their colors? 692. How

soft as wax. Some, as bismuth and antimony, are so brittle that they may be easily crushed in a mortar, while to pulverize gold or copper requires immense force. Their tenacity, which is determined by the amount of weight which wires of equal diameter will support, is also various. If lead be taken as 1, copper is 17 and iron 26. Heat generally diminishes the tenacity of metals, but in the case of iron and gold it increases it up to 212°.

**693. Malleability and Ductility.**—Malleable metals are those which may be hammered into thin leaves. Gold heads the list, and has been reduced to a film the $\frac{1}{200,000}$ of an inch in thickness. In ductility, or capability of being drawn into wire, platinum stands first. WOLLASTON produced wire from it but $\frac{1}{30,000}$ of an inch in diameter. The foregoing properties in each case vary with the texture of the metal.

**694. Specific Gravity.**—In this respect also there are great differences. While platinum is 22 times heavier than water, lithium is but little more than half as heavy as that liquid. The lightest metals have the strongest affinity for oxygen.

**695. Fusibility.**—The range of properties is here most remarkable. While mercury remains fluid at 39°, potassium and sodium fuse below the boiling point of water; silver and gold melt at a red heat, iron at a white heat (2,786°), and platinum only at the intense, but undertermined heat of the oxyhydrogen blowpipe.

**696. Volatility.**—Mercury vaporizes at 662°, and several metals are so volatile that they may be distilled from their compounds. Lead is largely volatilized, and copper slightly so in the smelting furnaces, and even gold is dissipated in vapor in the focus of a powerful burning glass. Some of the metals emit odors; arsenic gives the smell of garlic, while iron, tin, and copper by friction give forth distinctive odors.

**697. Conduction of Heat and Electricity.**—The metals are excellent conductors of heat and electricity, but vary in this respect. When separated from their compounds by electrolysis, they appear at the negative pole, and are hence electro-positive. It is remarkable that the vapors of the metals are non-conductors of electricity.

**698.** The metals occur in nature in three states. First, some

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do they vary in hardness, brittleness, and tenacity? 693. In malleability and ductility? 694. Specific gravity? Relation to affinity? 695. How do they differ in fusibility? 696. In volatility? 697. What is their relation to heat and

of them, as gold, silver, platinum, and mercury, are often found uncombined, and are said to occur in the *native state*. Second, many are found alloyed with each other, as gold and silver with mercury; but usually they occur in combination with the metalloids, for which they have a strong attraction. These compounds are known as *metallic ores*.

**699. Distribution.**—The soil and rocks beneath us, as has been stated, consist of metallic oxides, but the chief metals used in the arts are not so widely disseminated. They are found in various places and at various depths in the earth, in the form of seams, beds, or mineral veins. Fissures and openings among the older or fire-formed rocks often occur filled with ores, and are called *lodes*. The thickness and direction of veins are various, the most productive generally occurring near the junction of two dissimilar kinds of rock. It is supposed they are 'accumulated there in consequence of slow voltaic actions which have been going on through uncounted ages, and which have been occasioned by differences in chemical composition of the two contiguous rocks.' (Miller.) The ores are procured by excavating shafts in the earth, cutting horizontal or inclined galleries, and by picking, wedging, and blasting out the minerals.

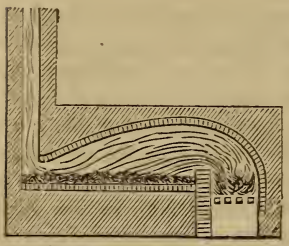
**700. Treatment of Ores.**—This is first mechanical, then chemical; the more valuable the ore, the more care does its management require, but the operations differ widely in different cases. The ores of lead and tin are dressed as follows: when brought to the surface, they are sorted, the purest lumps being set aside for the smelting furnace. The residue is then broken by hammers, and again sorted. The rougher portions are then crushed between revolving cylinders and the product passed through coarse sieves; while the finer part is agitated in water by the hand process of *jigging*. The crushing is completed in the *stamping mill*, which consists of upright, wooden beams, shod with iron and lifted by steam or water power, which are allowed to fall upon the ore. The products are repeatedly washed, and the powdered ores settle in layers according to their specific gravities.

**701. Roasting Ores.**—After ores have been prepared mechanically, they are subjected to chemical treatment, which is twofold

electricity? 698. In what three states are the metals found? 699. How do they usually occur? How are the veins formed? How worked? 700. How are lead and tin ores dressed? 701. When are metals roasted? How is it done? When is

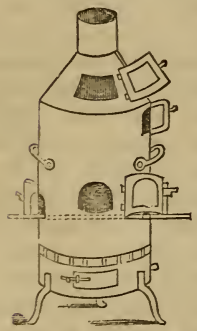
—*roasting* and *reducing*. If they contain volatile products, as sulphur or arsenic, which may be removed by oxidation or heat, they are first roasted. This is done in an oven-shaped furnace, called a *reverberatory*, Fig. 245. The fuel is placed at one end, and the heated gases and flame are *reverberated*, or thrown down from the arched roof of the furnace upon the ore, which is distributed over its bed. In this way ores are oxidized. If they contain sulphur, it burns off and escapes as sulphurous acid, while arsenic is carried away as arsenious acid. Sometimes, as in the case of lead, the metal is at once procured by the operation of roasting. In other instances it is changed to the state of oxide, and then requires another process to set it free.

Fig. 245.



Reverberatory Furnace.

Fig. 246.



Laboratory Furnace.

**702. Reduction or Smelting** of ores is the chemical process of deoxidation. It is effected by heating them to a high temperature in contact with substances which take the oxygen from the metal by superior affinity. Carbon is the chief deoxidizing agent, and removes the oxygen in the form of carbonic oxide and carbonic acid. For the removal of various earthy impurities, substances are employed termed *fluxes*, which, combining with them, melt and flow off as crude glass or *slag*. For laboratory operations with the metals, small furnaces are indispensable, such as those represented in Fig. 246.

## § II. *Theory and Constitution of Salts.*

**703.** Salts result from the union of non-metallic elements with the metals; they are therefore to be considered as compounds of the metals. It has been stated that salts are formed by the union

another process required? 702. What is smelting? How effected? For what is carbon used? What is the use of fluxes? 703. How are salts to be considered?

of acids and bases, but a more complete account of their consitution is now necessary.

**704. Two Kinds of Acids and Salts.**—When oxygen was discovered it was found by LAVOISIER to enter largely into the composition of acids; it was therefore believed to be the universal acidifying principle, and given a name which signifies *acid-former*. But it was afterward found that there are powerful acids, as the chlorohydric and iodohydric, which contain *no oxygen at all*, their common principle being hydrogen. Hence two kinds of acids were recognized, *oxacids* and *hydracids*.

**705.** In like manner it was at first supposed that all salts were double compounds, acid united to base, as sulphuric acid to potash, $KO, SO_3$. But it was at length discovered that this composition represents but a part of the salt family, and if adopted would exclude *common salt itself*, the very substance from which the term salt was derived. For, although common salt is produced by the addition of an acid and a base, chlorohydric acid to soda, yet there is not a simple *union* of the two binary compounds, but a *double decomposition*: the acid and the base are each split, and two compounds result; thus $NaO+HCl = NaCl+HO$. That is, when these substances are brought together, chloride of sodium and water are formed. Hence two kinds of salts are recognized, *oxysalts* and the *haloid* salts, or those which resemble common salt, from *hals*, salt. But it has been latterly maintained that there is only one type of acids and one of salts. DAVY started the hypothesis that all acids are properly *hydracids*, and all salts *binary*.

**706. The Later View of Acids.**—It is well known to chemists that when the oxacids, sulphuric, nitric, and phosphoric, are deprived of water, they no longer possess true acid properties. Sulphuric anhydride does not redden litmus, nor corrode the fingers; but if water be added, it instantly becomes a powerful acid. Now, as hydrogen is present in all the hydracids, and as the oxygen compounds only become acid by the addition of water *which contains hydrogen*, it is assumed that not oxygen, but *hydrogen* is the universal acidifying principle; and if there is but one acid-former, there is probably but one type of acids. The elements which combine with hydrogen to form acids are called *radicles*, as chlorine, iodine, &c.

704. What was the early idea of oxygen? What is now known? 705. What was the first idea of salts? What was at length discovered? Constitution of common salt. What is DAVY'S hypothesis? 706. Why has hydrogen been regarded as the

**707.** In speaking of cyanogen, it was stated that there is a class of compound bodies of which that substance is a type, which play the part of simple elements, and are called *compound radicles.* Cyanogen, $NC_2$, combines directly with hydrogen (like the simple radicle chlorine), to form cyanohydric acid, $HNC_2$. Now it is assumed that the oxacids contain compound radicles in the same way; and if this be admitted, the whole case is simplified. It is claimed that in sulphuric acid there is the radicle sulphion $SO_4$; in phosphoric acid, phosphion $PO_6$, and in nitric acid, nitration $NO_6$. These radicles unite with hydrogen, and thus the oxacids are binary. Sulphuric acid is sulphionide of hydrogen. The change is simple.

| OLD VIEW OF ACIDS. | | NEW VIEW. | | |
|---|---|---|---|---|
| Phosphoric acid, | $HO,PO_5$. | $H,PO_6$, | analogous to | H, Cy. |
| Sulphuric acid, | $HO,SO_3$. | $H,SO_4$, | " " | H, Cl. |
| Nitric acid, | $HO,NO_5$. | $H,NO_6$, | " " | H, Br. |

Hence we arrive at the following definition: *An acid is the hydrogen compound of a simple or compound radicle which possesses the power of neutralizing bases; its general formula being HR (hydrogen and radicle.)*

**708. Later View of Salts.**—From this point of view the composition of salts is also simplified; one type of acids gives us also one type of salts. By replacing the hydrogen of chlorohydric acid, HCl, by sodium, we get common salt, NaCl. By replacing the hydrogen of cyanohydric acid by potassium, we get the salt cyanide of potassium, $HNC_2$. And so by replacing the hydrogen of sulphionide of hydrogen by iron we get sulphionide of iron, $FeSO_4$, instead of the old sulphate, $FeO,SO_3$. On this view we may define a salt to be *the compound formed by replacing the hydrogen of an acid by a metal*; *and the general formula for a salt is MR (metal and radicle.)* (For diagrams rendering this subject easy of comprehension, see Author's Chemical Chart and Atlas.)

**709. Estimate of the Hypothesis.**—Although the foregoing hypothesis is ingenious and useful, and is perhaps growing in favor with progressive chemists, yet upon close examination, it is

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acidifying principle? What are radicles? 707. Compound radicles? Explain the new view of acids. What is the definition of an acid by this view? 708. According to this, how are salts formed? Give the definition of a salt. 709. What

found liable to objection, and, as remarked by Prof. Miller, cannot be considered as a correct representation of the composition of a salt under all circumstances. A salt, when once formed, may be regarded as a *whole;* it can no longer be looked upon as consisting of two distinct parts, but as a new substance maintained in its existing condition by the mutual action of all the elements which compose it. These different elements are not all united with each other in every direction with an equal amount of force. As a crystal cleaves in different directions as the force is differently applied, so a salt may split up into different simpler substances, according as the chemical force is applied one way or another. The probability therefore is, that neither the old nor the new view is absolutely correct, but that each may in turn well represent the salt when subjected to the influence of different forces.

**710. Sulpho-Salts.**—Sulphur is analogous to oxygen in chemical relations; and as there are oxysalts, so there is also a class of sulpho-salts, exactly corresponding to them in constitution.

**711. Normal Salts.**—The term *normal* salts has been applied to all those in which *there is an atom of acid for each atom of oxygen in the base.* Carbonate of potash, $KO, CO_2$, is an example. Where the base consists of a *sesquioxide* containing three atoms of oxygen, it requires three atoms of acid to form a normal salt. For example, alumina, $Al_2, O_3$, requires three atoms of sulphuric acid to form a normal sulphate of alumina, $Al_2, O_3, 3SO_3$.

**712.** If a solution of oxalic acid be added to that of potash in equivalent proportions, a neutral salt is formed. If this be redissolved, and another proportion of oxalic acid be added, it unites with the salt already formed, and an *acid* or *super-salt* is produced which reddens litmus and crystallizes in a different form from the first. *Basic* or *sub-salts* have an opposite structure—the base predominating over the acid. It has been stated that water in combination plays the part of both acid and base. With bases it unites as a feeble acid, and with acids as a feeble base. When one atom of water is combined with one of acid, it forms a *monobasic* acid; if two of water, a *bibasic* acid; and if several, a *polybasic* acid. Hence, by replacing the water of polybasic acids by metallic bases,

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does Prof. Miller say of this theory? 710. What are sulpho-salts? 711. What are normal salts? 712. What is a neutral salt? A super-salt? A sub-salt? When

we get *sub-salts* or *basic* salts. If different bases combine with polybasic acids, they produce *double* salts.

**713.** In crystallizing from aqueous solutions salts combine with a definite proportion of water, which is contained in the crystal as *water of crystallization.* Alum crystals contain nearly one half their weight of water. Certain crystals (Glauber's salts, for example), if exposed to the atmosphere, part with their combined water by evaporation, lose their brilliancy and crumble to a white powder; this is called *efflorescence.* Other salts when rapidly crystallizing confine mechanically in their texture a portion of the mother liquor, causing them when expanded by heat to explode with a crackling noise, which is termed *decrepitation.* Others, when exposed to the air, absorb water and become semi-liquid, the process being called *deliquescence.*

The salts that have been produced are already numbered by thousands, and there is no end to their multiplication. We shall have space to notice but a few, and those briefly.

## CHAPTER XIV.

### METALS WHICH DECOMPOSE WATER AT ORDINARY TEMPERATURES.

**714.** Authors vary in their classification of the metals, but they are usually arranged according to their affinity for oxygen. We shall divide them into three groups: first, metals which decompose water at common temperatures; second, metals which only decompose water at a red heat; third, metals which cannot decompose water at all. The first group comprises nine elements, as follows:—

| | |
|---|---|
| Potassium,<br>Cæsium,<br>Rubidium,<br>Sodium,<br>Lithium,<br>Barium,<br>Strontium,<br>Calcium,<br>Magnesium. | The first five metals of this group, when oxydated, produce alkalies, and are therefore called *metals of the alkalies.* The oxides of the remaining four are alkaline, though in a less degree, and have also an earthy appearance; hence they are termed *metals of the alkaline earths.* |

Is an acid said to be monobasic? When bibasic? When polybasic? 713. What is water of crystallization? What is effervescence? Decrepitation? Deliques-

## § I. *Metals of the Alkalies.*

### 1. POTASSIUM AND ITS COMPOUNDS.

*Potassium. Sym. K (Kalium). Equiv.* 39. *Sp. Gr.* 0.855.

**715. Potassium** was discovered by Sir HUMPHREY DAVY in 1807, together with sodium, barium, strontium, and calcium. Before that time the alkalies and alkaline earths had been considered as simple bodies, and the discovery of their compound nature forms an interesting era in chemical science. DAVY obtained this metal by subjecting moistened potash to the action of a powerful voltaic battery; the positive pole gave off oxygen, and metallic globules of pure potassium appeared at the negative pole.

**716.** It is never found free in nature, but occurs abundantly in rocks and soils combined with oxygen, as potash. It is usually obtained by the action of charcoal upon carbonate of potash at a very high temperature. The carbonate is decomposed, the free carbon seizing the oxygen of the potash and escaping as carbonic oxide, while the metal distils over into suitable condensers,

$$KO, CO_2 + 2C = K + 3CO.$$

**717. Properties.**—Potassium at common temperatures is a silver-white metal, and so soft that it may be moulded like wax. It has a powerful affinity for oxygen. If thrown upon the surface of water, instant decomposition takes place Fig. 247, the potassium uniting with the oxygen to form potash. The liberated hydrogen, together with a small quantity of volatilized metal, is ignited by the heat evolved during the decomposition, and burns with a beautiful lilac flame as the globule floats about on the surface of the liquid. Potassium decomposes nearly all compounds containing oxygen, if brought in contact with them at high temperatures, and many even at ordinary temperatures. Hence, to preserve it pure, it is kept in *naphtha*, a liquid containing no oxygen.

FIG. 247.

Combustion of Potassium.

cence? 714. How are the metals classified? How is group first divided? 715. When and by whom was potassium discovered? By what means? What was the effect of the discovery? 716. How does it occur in nature? How is it obtained? 717. What are its properties? Why is it kept in naphtha?

**718. Protoxide of Potassium,** KO (*Potash*).—This, the most important compound of potassium, is always formed when the metal comes in contact with free oxygen. It has a powerful attraction for water, absorbing it with avidity when exposed to a moist atmosphere, and forming a hydrate, or *caustic potash*, KO, HO. This is generally procured by the action of caustic lime in a boiling solution of carbonated potash. The lime unites with the carbonic acid of the potash, forming insoluble carbonate of lime, which subsides. The clear liquid, containing the potash in solution, is then drawn off and concentrated by evaporation. If the heat be continued to a point little short of redness, the liquid flows without ebullition, and may then be run into moulds, where it solidifies on cooling, forming the small, grayish-white sticks of commerce.

**719.** Potash possesses all the properties of the alkalies in a pre-eminent degree. It saturates the most powerful acids, changes vegetable yellows to brown, restores the blues discharged by acids, and decomposes animal and vegetable substances, whether living or dead. It is used in medicine to cauterize and cleanse ulcers and foul sores; hence its name, *caustic potash*. If a solution of potash be shaken in a bottle with any fixed oil, the two unite, forming a *soap*. This accounts for the soft greasy feel it has when touched by the fingers, as it decomposes the skin and forms a soap with its oily elements. When taken into the system, potash acts as a powerfully corrosive poison. Its active chemical character renders it an indispensable reagent in the laboratory.

**720. Iodide of Potassium,** KI (*Hydriodate of Potash*).—This may be formed by adding iodine to a solution of potash, and gently warming until the solution assumes a brown tint. It is a very soluble, white solid, which crystallizes in cubes, and is much used in medicine.

**721. Carbonate of Potash,** $KO,CO_2$.—Potash exists in plants in combination with various organic acids. When the plant is burned, these combinations are broken up; the organic acids are decomposed into carbonic acid and water, and the liberated potash unites with a portion of the carbonic acid formed by combus-

718. What is potash? Hydrate of potash? How is caustic potash obtained? 719. What are its properties? What is its action with oils? Its uses in medicine? In the laboratory? 720. What is iodide of potassium? Its uses? 721. How is

tion, thus producing carbonate of potash. This is a highly alkaline, deliquescent salt, and is used largely in the manufacture of soap and glass, in preparing caustic potash, &c. It is also an important reagent in the laboratory, and is a most valuable fertilizer. This salt rarely forms less than 20 per cent., and sometimes more than 50 per cent. of the weight of wood ashes. The ashes of different plants, and even different parts of the same plant, yield it in varying amounts. Wood ashes furnish the principal source of the carbonate of potash of commerce, from which it is obtained by leaching them and boiling the solution to dryness in iron pots. The residue is called *potashes*, and these, when calcined, afford the impure carbonate known as *pearlash*. Potash, or pearlash, therefore represents the readily soluble portion of wood ashes, and consists chiefly of carbonate of potash with small amounts of carbonate of soda and common salt.

722. **Bicarbonate of Potash,** $KO,2CO_2$.—This is formed by passing carbonic acid through a strong solution of carbonate of potash, which combines with a second equivalent of the acid. It is employed as a source of potash in the formation of many of its other compounds, and is also used for making effervescing draughts by adding citric or tartaric acid to its solution, which, combining with alkali, sets the gas free.

723. **Nitrate of Potash,** $KO,NO_5$ (*Nitre*, *Saltpetre*).—This salt occurs as a native product in the earth of various districts in the East Indies, and is separated therefrom by leaching the soil, and allowing the nitre to crystallize. It is artificially formed by heaping up organic matter with lime, ashes, and soil, and keeping the mass well moistened with urine for a period of two or three years, when the heap is lixiviated and the salt crystallized out. Besides these sources, nitre occurs in the sap of certain plants, such as the sunflower, tobacco plant, &c.

724. Nitre dissolves in about three times its weight of cold and one third its weight of boiling water. It is rich in oxygen, and when thrown upon burning charcoal is decomposed and deflagrates violently. Paper dipped in this solution, and dried, forms what is known as *touch paper*. When ignited, it burns slowly and

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carbonate of potash obtained? State the properties and uses of the salt? How do its proportions vary in different ashes? What is pearlash? For what used? 722. What is bicarbonate of potash? Its uses? 723. How does nitrate of potash occur? Explain its artificial formation. From what other sources obtained?

steadily until consumed; hence its use in lighting trains of gunpowder, fireworks, &c. Nitre has a cooling, saline taste and strong antiseptic powers. Owing to the latter quality it is used extensively in packing meat, to which it imparts a ruddy color. It is chiefly consumed, however, in the manufacture of gunpowder; the large amount of oxygen it contains, and the feeble affinity by which it is held, adapting it for sudden and rapid combustion.

**725. Gunpowder** is an intimate mechanical mixture of about 1 part nitre, 1 part sulphur, and 3 parts charcoal. These proportions, however, vary somewhat in different countries, as well as in different sorts of powder. More charcoal adds to its power, but also causes it to attract moisture from the air, which of course injures its quality. For blasting rocks, where a sustained force, rather than an instantaneous one, is required, the powder contains more sulphur, and is even then often mixed with sawdust to retard the explosion.

**726. Manufacture.**—The nitre, sulphur, and charcoal, having been ground and sifted separately, are thoroughly mixed and then made into a thick paste with water. This is ground for some hours under edge stones, after which it is subjected to immense pressure between gunmetal plates, forming what is known as *press-cake*. These cakes are then submitted to the action of toothed rollers, whereby the granulation of the powder is effected. The grains thus formed are sorted into different sizes by means of a series of sieves, and thoroughly dried at a steam heat. The last operation, that of polishing, is accomplished in revolving barrels, after which the powder is ready for market. The heavier the powder, the greater is its explosive power. Good powder should resist pressure between the fingers, giving no dust when rubbed, and have a slightly glossy aspect. The explosive power of gunpowder is due to a sudden formation of a large volume of nitrogen and carbonic acid gas; one volume of the powder giving about 1,800 volumes of vapor. *Fireworks* contain nitre as a chief ingredient, mixed with charcoal, sulphur, ground gunpowder, and various coloring substances.

**727. Chlorate of Potash,** KO, $ClO_5$.—This may be formed by

724. What is touch paper? For what used? What are the uses of nitre? 725. What is gunpowder? How may its properties be varied? 726. Describe its manufacture? How may good powder be distinguished? To what is the explosive

passing chlorine gas through a solution of carbonate of potash. Chlorate of potash is soluble in water, has a taste resembling that of nitre, melts at about 700°, and, if heated above that temperature, parts with its oxygen. It is used in the manufacture of lucifer matches, in certain operations of calico printing, and as a source of oxygen.

## 2. SODIUM AND ITS COMPOUNDS.

*Sodium, Sym. Na. (Natrium). Equiv.* 23. *Sp. Gr.* 972.

**728.** Sodium closely resembles potassium in both appearance and properties. It is prepared in the same manner from its carbonate, and like potassium, must be kept in naphtha to prevent its oxidation. When freshly cut it presents a silvery appearance, and if cast upon hot water bursts into a beautiful yellow flame, and is converted into oxide of sodium, or soda; the same reaction taking place as in the case of potassium. Sodium is a very abundant metal, constituting more than two fifths of common salt, and existing as a large ingredient of rocks and soils.

**729. Oxide of Sodium,** NaO (*Soda*).—This compound of sodium strongly resembles the corresponding one of potassium, though its properties are somewhat less marked. For commercial purposes it is chiefly obtained from common salt. Soda, like potash, attracts moisture from the air, forming a hydrate. It results from recent discoveries in spectrum analysis (346), that compounds of sodium are almost everywhere diffused. They are found in the atmosphere, and in particles of dust; indeed it seems that we can hardly touch any substance without imparting to it a little soda salt from our hands.

**730. Chloride of Sodium,** NaCl (*Common Salt*).—This well known substance needs little description. It exists in great abundance both in solution and as a solid. Sea water contains in every gallon about 4 ounces of salt. Estimating the ocean at an average depth of two miles (Lyell), the salt it holds in solution would, if separated, form a solid stratum 140 feet thick. Saline springs in various localities in this country yield enormous quantities of salt by the process of evaporation. The springs in the State

power due? What is the composition of fireworks? 727. Give the composition and properties of chlorate of potash. For what is it used? 728. What is sodium? State its properties. 729. What is the composition of soda? Its sources? 730.

of New York alone furnish an annual supply of about 6,000,000 bushels. As a solid it occurs in extensive beds in various localities in Europe. The celebrated bed at Wielitzka, Poland, is said to be 500 miles long, 20 miles broad, and 1,200 feet thick, containing salt enough to supply the entire world for thousands of years.

**731.** Salt exists in small quantities in plants, and sometimes promotes their growth by being applied to the soil. It is also an ingredient of animal bodies, being contained in the blood. It forms an important constituent of the food of both man and beast, an adult consuming (as estimated by PEREIRA) about five ounces per week.

FIG. 248.

FIG. 249.

FIG. 250.

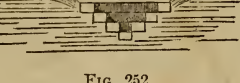
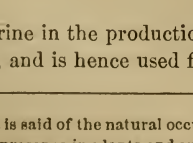


FIG. 251.

FIG. 252.



Crystallization of Common Salt.

**732.** Common salt is readily soluble alike in hot or cold water, and usually crystallizes in cubes. A peculiar-shaped crystal, or aggregation of crystals, is often formed when the salt is allowed to crystallize from concentrated solutions. A small cube is first formed which sinks so as to bring its upper surface on a level, or a little below the surface of the water, Fig. 248. Other cubes form on this, and as the mass sinks, still others are deposited, each layer being attached to the upper and outer edge of the layer next below, until a form like that seen in Fig. 252 is obtained.

**733.** Salt is used for packing and preserving meat, as it prevents putrefaction, by absorbing water from the flesh (1127). It is also used as a source of sodium in the manufacture of caustic soda, and as a source of chlorine in the production of chlorohydric acid. It fuses at a red heat, and is hence used for glazing stoneware, earthenware, &c.

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What is said of the natural occurrence and abundance of common salt? 731. What of its presence in plants and animals? 732. State its properties. Mode of crystal-

**734. Iodide and Bromide of Sodium,** NaI, NaBr.—These compounds are formed in sea water, and are interesting only as being the commercial sources of iodine and bromine.

**735. Carbonate of Soda,** $NaO, CO_2 + 10HO$.—Soda is supposed to fill the place in marine plants that potash does in land plants, and its carbonate was formerly obtained by leaching their ashes. It is now manufactured almost entirely from common salt by LEBLANC's process. This consists first in treating chloride of sodium with sulphuric acid, forming sulphate of soda, or *salt cake*, and chlorohydric acid. The next step in the process is the substitution of carbonic acid for the sulphuric acid in combination with the soda. This is effected by heating the salt cake with finely ground coal and chalk in a reverberatory furnace constructed for the purpose. After the mass is thoroughly fused, it is raked out into wooden troughs and allowed to cool, forming *ball soda*, or *black ash*.

**736.** In this operation the carbon unites with the oxygen of the sulphate of soda, thus forming carbonic oxide which escapes, leaving sulphide of sodium. An interchange now takes place between the carbonate of lime and the sulphide of sodium, carbonate of soda and sulphide of calcium being the result. In symbols,

$$NaO, SO_3 + CaO, CO_2 + 4C = NaO, CO_2 + CaS + 4CO.$$

The carbonate of soda, being the only constituent of the black ash that is readily soluble, is separated by leaching with warm water; and lastly, the solution is evaporated to dryness, yielding the soda ash, or crude carbonate of commerce. Carbonate of soda is extensively used in the manufacture of soap and glass, being both cheaper and purer than the ordinary potash. It is also used as a detergent, both in calico printing and in the laundry.

**737. Bicarbonate of Soda,** $NaO, 2CO_2, HO$.—This is produced by passing carbonic acid through a solution of the carbonate. It forms the effervescing soda powders, and is used in bread making.

**738. Sulphate of Soda,** $NaO, SO_3 + 10HO$ (*Glauber's salt*).—This well-known salt may be formed by adding sulphuric acid to soda, and is chiefly procured in the manufacture of chlorohydric

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lization. 733. What are its uses? 734. What is said of iodide and bromide of sodium? 735. How was carbonate of soda formerly obtained? How at present? 736. Explain the changes. Uses of the salt. 737. What is bicarbonate of soda?

acid. It has a bitter saline taste, and loses its water of crystallization on exposure to the air.

**739. Nitrate of Soda,** $NaO, NO_5$ (*Soda-Saltpetre, Cubic Nitre*).—Procured native from parts of Brazil and Chili. Attempts have been made to substitute this salt for nitrate of potash in the manufacture of gunpowder, but its tendency to attract moisture from the air has rendered it impracticable. Nitric acid is obtained from it, and it has been somewhat used as a fertilizer.

**740. Biborate of Soda,** $NaO, 2BO_3 + 10HO$ (*Borax*).—This is obtained from the evaporation of the waters of several lakes in Thibet. It is procured artificially by heating boracic acid with carbonate of soda, the carbonic acid being expelled, and the boracic acid taking its place. This salt has an alkaline taste and reaction, and possesses the property of dissolving many metallic oxides; hence, its use as a flux in the welding of metals. It dissolves off the coating of oxide formed when they are heated, thus presenting a clean surface.

### 3. MANUFACTURE OF GLASS.

**741.** When pure sand is heated with potash or soda, they fuse into a viscous, transparent mass before passing into the form of a liquid. While in this state they may be moulded into any desired shape, retaining their form and transparency when cold. When the alkaline earths are heated with them, they are brought into the same condition. Thus we have a compound easily moulded at a certain stage of fusion, uncrystalline when cold, but transparent, hard, strong, insoluble and durable—that is, common glass.

**742. Materials of the Manufacture.**—These are, first, *silica*, in the shape of pulverized quartz or sand. For the manufacture of the finest varieties of glass a pure white sand free from oxide of iron is employed. Second, there are the basic constituents of potash, soda, lime, magnesia, and oxide of lead, more or less pure, according to the quality of the glass required. Metallic oxides are employed as coloring agents.

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738. What is sulphate of soda? 739. Nitrate of soda? 740. Give the composition of biborate of soda. Its uses. 741. When silica is heated with potash or soda, what results? When with alkaline earths? What are the properties of the compound? 742. What is the composition of glass? 743. Describe the process. How

**743. Process.**—These materials are placed in pots or crucibles of refractory fire-clay, and several of them set in a large conical furnace. The fire is kept up day and night for months, the materials being added and withdrawn at pleasure. The plastic nature of the half-fused product adapts it for being easily worked into all desirable forms. The workman dips an iron tube four or five feet in length into the waxy material, a portion of which adheres to it. To give it regular shape, he rolls it upon an even surface, Fig. 253; and to make it hollow, he blows through the tube. The glass may be pressed into various shapes between two moulds, one of which shuts into the other. Or it may be worked into globes and cylinders. If common window glass is to be made, the rounded mass upon the tube is blown into a pear shape, Fig. 254, which becomes elongated by swinging backward and forward, like a pendulum. By reheating, blowing and rolling, it is worked into the form of a cylinder, Fig. 255, which is cut off at *a* and *b*, and split along the line *e*. After again softening in the furnace, the cylinder is opened and spread out into a flat plate, as shown in Fig. 256.

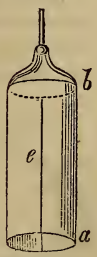
Fig. 253.

Rolling Melted Glass.

Fig. 254.

Blowing Glass.

Fig. 255.




Glass Cylinder.

**744. Colored Glass.**—The coloring of glass is effected by fusing into the materials a small quantity of metallic oxide. Oxide of copper gives a green tinge; oxide of gold a ruby color; oxide of uranium a yellow; oxide of cobalt a deep blue; oxide of manganese a purple; while a mixture of the oxides of cobalt and manganese produces a black glass. Enamel watch-dials and semi-opaque transparencies are glass rendered milk white by oxide of tin, or bone earth.

**745. Varieties of Glass.**—The silicates of lime, magnesia, iron, soda, and potash, in their impure form, produce the coarser kinds of glass of which green bottles are made. The silicates of soda and lime give the common window glass and French plate. Lime hardens glass, and adds to its lustre; soda tends to

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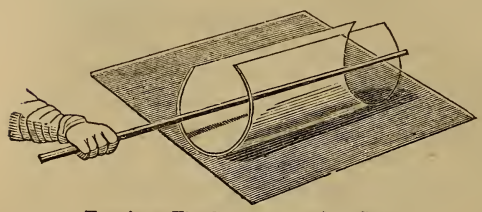
are the various forms obtained? 744. How are the different colors produced? 745. Of what does bottle glass consist? Window glass? What is the effect of lime?

give it a greenish tinge. *Bohemian glass*, the most beautiful variety, hard and highly infusible, is a silicate of potash and lime.

**746. Imitation of Precious Gems.**—*Crystal glass*, or *flint glass*, so called because pulverized flints were formerly used in making it, is a compound of the silicate of potash and lead. The oxide of lead renders it very soft so as to be easily scratched, but greatly reduces its transparency, brilliancy, and refractive power. Sometimes the proportion of oxide of lead rises as high as 53 per cent. Glass of this composition forms what is called *paste*, and, when suitably cut, is used to imitate the diamond. By the addition of a trace of oxide of iron the yellow of the topaz is imitated, and by oxide of cobalt the brilliant blue of the sapphire is produced.

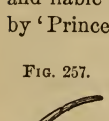
Fig. 256.



Forming a Flat Sheet of Window Glass.

**747. Annealing Glass.**—If glass is suddenly cooled after fusion, there seems an unequal strain upon its particles, and it is brittle and liable to crack on the slightest scratch or jar. This is shown by 'Prince Rupert's drops,' little pear-shaped bodies, Fig. 257, made by dropping globules of melted glass into water. The cooling of the outer particles while the inner ones are still fluid, prevents the latter from expanding as they cool, thus causing such an enormous strain upon the surface, that if the small end be nipped off, the whole mass flies to pieces with an explosion. To obviate this difficulty, glass, after having received the desired form, is placed in large furnaces, which are maintained at a gradually decreasing heat for several days, until quite cool. This process is called *annealing*. Glass is cut by the diamond, and holes may be bored through it with the end of a three-cornered file, if the point of friction be kept wet with spirits of turpentine.

Fig. 257.



Rupert's Drops.

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746. What is flint glass? What is the effect of lead upon it? What is paste? 747. Why must glass be annealed? How is it done? How is glass cut and bored? 748.

## 4. CÆSIUM, RUBIDIUM, LITHIUM, AMMONIUM.

### CÆSIUM.

*Sym. Cs. Equiv.* 123.4.

**748.** The extraordinary circumstances under which this metal and rubidium were discovered have been already stated (366). By evaporating a large quantity of the water containing cæsium, BUNSEN obtained a small amount of it as a chloride, and afterward as an amalgam, with mercury. Such is its affinity for oxygen, that even in the state of alloy it oxidizes in the air and decomposes cold water. It is the most electro-positive element known, surpassing potassium, which formerly ranked first in this respect. It forms extremely caustic hydrates and carbonates, while its bicarbonate occurs in permanent, glassy crystals.

### RUBIDIUM.

*Sym. Rb. Equiv.* 85.36.

**749.** This new metal has analogous properties with the preceding. It is silver-white in color, with a crystalline structure, and forms compounds similar to those of cæsium. GRANDEAU has lately detected rubidium in the ashes of beets, tobacco, tea, and coffee. These metals are found associated with potassium, which they closely resemble, and are obtained in considerable quantity from the mineral *Lepidolite.*

### LITHIUM.

*Sym. L. Equiv.* 7. *Sp. Gr.* 0.5936.

**750.** This metal resembles potassium and sodium, though somewhat harder and considerably lighter, being the lightest metal known. Until recently, it was supposed to be very rare, but the late researches of BUNSEN and KIRCHOFF show that it is quite abundant and widely distributed. By the spectrum analysis they have found it in sea-water, in the water of springs, in the ashes of plants, and in the human blood.

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What are the properties of cæsium? 749. What of rubidium? Whence is it obtained? 750. What are the properties of lithium? Is it abundant? 751. Why is ammonium believed to exist? What is its theory? 752. What are the

## AMMONIUM.

*Sym.* $H_4N$. *Equiv.* 18.

**751.** This is believed to be a compound radicle, having the nature of a metal, and forming oxides, salts, and even an amalgam. Thus hydrated ammonia, $H_3N,HO$, is regarded as an oxide of ammonium, $H_4N,O$. It has never been separated. But if an amalgam of potassium and mercury be placed in a solution of sal ammoniac (752), it swells up, assumes a pasty consistence, *but preserves its metallic lustre and the character of an amalgam.* It is held that the potassium of the first amalgam has been replaced by ammonium, which has analogous metallic properties. The new amalgam rapidly decomposes into mercury, *ammonia, and hydrogen.*

**752. Chloride of Ammonium,** $H_4N$, Cl (*Sal Ammoniac*).—A solution of ammonia is neutralized by chlorohydric acid, crystals of chloride of ammonium being produced, which have a sharp taste, and dissolve in thrice their weight of cold water. Sal ammoniac is chiefly obtained by neutralizing the ammoniacal liquor of the gas works by chlorohydric acid. On evaporating the liquor the salt appears in the form of the tough, fibrous crystals of commerce. It is volatilized by heat. It is used in soldering to cleanse metallic surfaces, the chlorohydric acid dissolving the coat of oxide. Mixed with lime, which decomposes it and expels the ammonia, it is used to fill smelling bottles.

**753. Carbonate of Oxide of Ammonium** (*Carbonate of Ammonia*).—There are several of these salts. Pure ammonia and carbonic anhydride unite to form a neutral, anhydrous carbonate, $H_3N$, $CO_2$, pungent, volatile and very soluble in water. The common *sal volatile*, or smelling salts of the shops, is a sesquicarbonate $2H_4NO,3CO_2$.

**754. Sulphate of Oxide of Ammonium,** $H_4NO,SO_3HO$, is prepared in a large way by neutralizing the ammoniacal liquor of the gas works with sulphuric acid. It is a valuable fertilizer. Nitrate of oxide of ammonium $H_4NO,NO_5,HO$, is a soluble salt used as a source of nitrous oxide. There is a host of compounds of ammonia which are of interest only to the professed chemist. The ammoniacal salts are all soluble, and yield the ammoniacal odor by adding caustic lime or potash, or at a high heat.

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properties of chloride of ammonium? Its uses? 753. What carbonates are mentioned? 754. What other salts of ammonia? 755. What is barium?

## § II. *Metals of the Alkaline Earths.*

### BARIUM.

*Sym. Ba. Equiv.* 68.6.

**755.** Barium occurs in large quantity in the mineral known as heavy spar (sulphate of baryta). It is a white, silver-like metal, and has a strong affinity for oxygen, tarnishing on exposure to the air.

**756. Oxide of Barium,** BaO (*Baryta*), is a gray powder having a strong attraction for water, which it absorbs on exposure to the air, forming hydrate of baryta. The hydrate has an alkaline reaction, and unites with acids to form salts.

**757. Chloride of Barium,** BaCl+2HO.—This salt is readily soluble in water. It is interesting only as being the usual test for sulphuric acid, with which it gives a dense white, insoluble precipitate of sulphate of baryta.

**758. Sulphate of Baryta,** $BaO, SO_3$ (*Heavy Spar*).—This mineral occurs in large quantities, and when ground is extensively consumed under the name of barytes in the adulteration of paints. *Carbonate of baryta*, $BaO, CO_2$, is always formed when caustic baryta is exposed to the air. It occurs native in abundance, and is the chief source of the compounds of baryta. All the soluble salts of baryta act as powerful poisons when taken into the system.

### STRONTIUM.

*Sym. Sr. Equiv.* 43.8.

**759.** This metal resembles barium, in both appearance and properties. The nitrate of strontia is used considerably in the preparation of fire works, to the flames of which it imparts a beautiful crimson color.

### CALCIUM.

*Sym. Ca. Equiv.* 20. *Sp. Gr.* 1.57.

**760.** Calcium is a light yellow metal, somewhat harder than lead, very malleable, melts at a red heat, and oxidizes in the air. It exists in abundance in limestone, fluor spar, and gypsum.

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756. Oxide of barium? 757. State the properties of chloride of barium? Its use? 758. What is said of sulphate of baryta? What of carbonate? 759. Mention the uses of strontium? 760. What is calcium? Where is it found? 761. What is the

**761. Oxide of Calcium, CaO (*Lime*).**—Calcium forms but one oxide, the well-known substance lime, which exists in such vast quantities in combination with carbonic acid as limestone, and with sulphuric acid as gypsum. Lime is prepared by burning limestone in large masses in kilns. The carbonic acid is driven off into the air by the heat, and a white, stony substance remains, called *quick* lime, or *caustic* lime. One ton of good limestone yields 11 cwt. of lime. When this is exposed to the air it first rapidly imbibes moisture and crumbles to powder. This gradually absorbs carbonic acid, and becoming less and less caustic, regains the neutral condition of the carbonate.

**762. Properties.**—Lime exhibits the properties of a strong alkali, decomposing organic tissues and saturating the strongest acids. It is more soluble in cold than in hot water. Hence, when a cold saturated solution of lime-water is boiled, a portion of the lime is deposited, which accounts for the crust or fur which lines the interior of tea-kettles in localities where the water is impregnated with lime.

**763.** Lime exists extensively in organized structures. The mineral portion of the skeleton of the higher animals consists of lime combined with phosphoric acid, and it is contained in the shells of the lower animals, chiefly united with carbonic acid. It also forms a large ingredient of plants. Lime is to be found in most fertile soils, and is much used in agriculture, as it promotes the decomposition of organic and inorganic matter, thus fitting it for assimilation by plants.

**764. Hydrate of Lime.**—When water is poured upon quicklime it absorbs it (every 28 lbs. of lime taking nine pounds of water), swells to thrice its original bulk, crumbles to a fine white powder, and is converted into a hydrate of lime, CaO, HO. This process is called *slaking*, and sufficient heat is often produced by the chemical action to ignite wood. *Lime water* is a saturated, transparent solution of lime in water. *Cream* or *milk of lime* is a thick mixture of the hydrate with water, such as is used in whitewashing. In tanneries the hides are immersed in milk of lime,

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composition of lime? How is it obtained? What is the effect of exposure to the air? 762. State the properties of lime. Explain the cause of the crust of tea-kettles. 763. Where is lime found in organic structures? What are its uses in agriculture? 764. How is the hydrate obtained? What is lime water? Milk of lime? Its uses? 765. Of what is the best mortar made? What is the effect of

which partially decomposes them, so that the hair may be easily removed.

**765. Mortar and Cement.**—Lime, mixed with sand, forms the mortar employed by builders to cement stones and bricks. To make the best mortar, the lime should be perfectly caustic and the sand sharp and coarse-grained. The nature of the changes by which the mortar becomes hardened is not satisfactorily explained. It is supposed to be owing in part to the lime absorbing carbonic acid from the air, and hardening into a carbonate of lime. In time the lime also partially combines with the silica of the sand, forming an exceedingly hard silicate of lime. Common mortar, when laid in water, not only refuses to harden, but its lime gradually becomes dissolved out and washed away. *Hydraulic cement* possesses the property of solidifying under water. This quality is owing to the presence of clay (silicate of alumina) in the lime of which it is composed.

**766. Carbonate of Lime,** $CaO, CO_2$.—Vast deposits of this salt are distributed all over the globe in the form of limestones, marbles, chalks, marls, coral-reefs, shells, &c. Numerous and extensive as are these deposits, it is conjectured that they are all of animal origin. The densest limestone and the softest chalk are found to consist of the aggregated skeletons, or shells of myriads of tribes of the lower animals, which have existed in some former period of the world's history. The formation of coral reefs, which are sea-islands of carbonate of lime built up from the depths of the ocean by minute aquatic animals, is an example of similar deposits now in process of formation.

**767.** Carbonate of lime is decomposed by heat into carbonic acid and lime. It is soluble in water containing free carbonic acid; hence the well and spring water of lime districts becomes impregnated with it, hard water being the result. When the hardness of water is due to this cause, it may be softened by the addition of lime water, which neutralizes the excess of carbonic acid, the carbonate being precipitated. Water containing carbonate of lime in solution deposits a portion of it on free exposure to the air. Examples of this are often seen in caves. The water, as it trickles from fissures in the roof, deposits its carbonate

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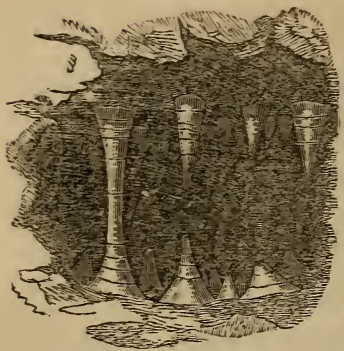
time upon it? What is hydraulic cement? 766. What forms of carbonate of lime exist naturally? What is the origin of these deposits? What of coral-reefs? 767. What is the effect of heat upon carbonate of lime? How may hard water be

Fig. 258.



Effects of lime in caves.

until pendent masses like those represented in Fig. 258 are formed. These are called *stalactites*, and where the water strikes on falling, other forms similar to those above gradually grow up from the floor, and are known as *stalagmites*. These often unite, thus forming a column.

**768. Sulphate of Lime,** $CaO, SO_3 + 2HO$ (*Gypsum*, *Plaster*, *Alabaster*).—This salt occurs in many parts of the world, forming extensive rocky beds. In its pure, transparent form, it is known as *selenite*, and in its compact and earthy varieties as gypsum, plaster of Paris, and alabaster. When powdered gypsum is heated to nearly 300°, it parts with its water of crystallization. If now it is made into a liquid paste with water, it again combines with it, and speedily hardens or *sets*, resuming its stony aspect. Owing to this property, it is used to take impressions of objects and make casts, by being run into hollow moulds. Colored and mixed with glue, it is used for the ornamental designs in architecture called *stucco-work*. Gypsum is used extensively as a fertilizer.

## MAGNESIUM.

*Sym. Mg. Equiv.* 12. *Sp. Gr.* 1.7.

**769.** This is a white, brilliant, malleable metal, found abundantly in combination in many rocks and minerals, and occurs also in sea-water as a chloride.

**770. Oxide of Magnesium,** MgO (*Magnesia*).—Only one oxide of magnesium is known, and this is found by igniting the carbonate. It is a white, light powder, with feeble alkaline properties, very sparingly soluble in water, but dissolving readily in acids. It is found in some minerals, in mineral waters, and in the

softened? What are stalactites? Stalagmites? 768. Give composition of sulphate of lime. How does it occur? What is selenite? Use of gypsum for making casts? What are its other uses? 769. Describe magnesium. 770. State the

ash of nearly all plants. In medicine it is used as a mild aperient and antacid.

**771. Sulphate of Magnesia,** $MgO, SO_3 + 7HO$ (*Epsom Salts*).—This is a common ingredient of mineral waters, and takes its name from the circumstance of its being contained in great quantities in the springs near Epsom, in England. The commercial supply is chiefly derived from sea-water, by precipitating the magnesia with lime, and then adding sulphuric acid. It may also be obtained from magnesian limestone. It is soluble in water, has a bitter, saline taste, and is used in medicine as a cathartic and an antidote to various poisons. It has also been used as a fertilizer.

# CHAPTER XV.

METALS WHICH DECOMPOSE WATER AT A RED HEAT.

| | | |
|---|---|---|
| Aluminum, | Cerium, | |
| Glucinum, | Iron, | The first ten metals |
| Thorinum, | Manganese, | of this group are metals |
| Yttrium, | Nickel, | of the earths, but with |
| Erbium, | Cobalt, | the exception of alu- |
| Terbium, | Zinc, | minum, they are very |
| Zirconium, | Cadmium, | rare, and of no special |
| Lanthanum, | Tin. | interest. |
| Didymium, | | |

## § 1. *Aluminum and its Compounds.*

### ALUMINUM.

*Sym. Al. Equiv.* 13.7. *Sp. Gr.* 2.5.

**772.** This important metal was discovered by the German chemist, Wöhler, in 1827. It is found in nature in immense quantities, being the metallic base of alumina which forms the argillaceous rocks, beds of clay, and a large proportion of granite. It is a shining, white metal, of a shade between silver and pla-

properties of magnesia. Where is it found? Its uses? 771. What is sulphate of magnesia? What are its properties? Its uses? 772. Discovery of aluminum.

tinum, harder than zinc, lighter than glass, and of remarkable strength and stiffness. It resists the oxidizing influence of moist air like silver, melts at a still lower temperature than that metal, and, pound for pound, occupies four times its space. It is more sonorous than any other metal, giving forth a clear musical sound when struck. It is malleable and ductile like iron, exceeds it in tenacity, and combines with carbon, forming a cast metal which is not malleable. It resists the action of cold nitric and sulphuric acids, and, unlike silver, is not tarnished by sulphuretted hydrogen. It dissolves in chlorohydric acid, forming a chloride, and conducts electricity nearly as well as silver. Aluminum is obtained by decomposing chloride of aluminum by means of sodium, and as sodium is at present expensive, the manufacture of aluminum renders it a costly metal ($4 per lb.). It will undoubtedly be greatly cheapened, when it will become of invaluable service in the arts. Its alloys will be noticed in Chap. XVII.

**773. Sesquioxide of Aluminum,** $Al_2O_3$, (*Alumina*).—This, which is the only oxide of alumina, is an abundant natural product, being found in all soils and rocks. Crystallized and colored by oxide of chromium, it forms the ruby and sapphire, which rank next to the diamond in hardness and value. In a more massive form it is known as *corundum*. Alumina seems to possess the properties of both an acid and a base, uniting with either to form definite salts. It has a powerful attraction both for vegetable coloring matter and for the fibre of cloth; hence, it is used by dyers to fix the colors upon their fabrics. It is then said to act as a *mordant*. Alumina is precipitated from organic solution by an alkali, and, if there is any vegetable or animal coloring matter present, this is also carried down with the alumina, forming what is termed a *lake*. Carmine is a lake of cochineal. Alumina also absorbs and combines with oily matters; hence, a certain kind of clay, called *fullers' earth*, is used to extract grease from wood, paper, &c.

**774. Sulphate of Alumina and Potash,** $KO, SO_3 + Al_2O_3, 3SO_3 + 24HO$ (*Alum*).—Small quantities of this important salt are found native, but for commercial purposes it is prepared artificially by

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Where does it occur? What are its properties? How is it obtained? Its price? 773. What is alumina? Mention some of its varieties. Its properties. How is it used by dyers? How is carmine formed? What is fullers' earth? 774. Give the composition of alum. How is it formed? 775. Its properties? What is burnt

several different methods. In this country it is formed by treating alumina or clay with sulphuric acid, and, after the lapse of a few months, adding potash, either in the form of sulphate or carbonate. The whole is then leached, and the alum separated from the solution by crystallization.

**775.** Alum has a sweetish, styptic taste, and is soluble in 18 parts of cold water, or in its own weight of boiling water, the solution having an acid reaction. When heated, alum swells up into a light, puffy condition, at the same time giving off its water of crystallization, and leaving a white, anhydrous, infusible mass known as *burnt alum*.

**776.** Alum is used largely for purifying and preserving skins, for mordants in dyeing and calico printing, for glazing paper, for hardening and whitening tallow, clarifying liquors, and in medicine as an astringent and caustic. Wood impregnated with it is almost incombustible.

**777.** Sulphate of soda or ammonia may replace the sulphate of potash in combination with the alumina, thus giving a soda or ammonia alum. In like manner the sesquioxides of iron, manganese, chromium, &c., being isomorphous with alumina, may replace it, forming an iron, manganese or chrome alum, all of which have the same crystalline form.

**778. Silicate of Alumina, or Clay,** is the result of the decomposition of feldspathic and silicious rocks, and is the basis of all kinds of pottery. Its adaptation for this purpose depends upon its plasticity when mixed with water, the readiness with which it may be moulded, and also upon its capability of solidifying when exposed to a high heat. After burning, the ware, though hard, is porous, and absorbs water with avidity, even allowing it to filter through. To prevent this, the ware is covered with a glassy coating, or glazed.

**779. Porcelain** consists of a mixture of decomposed feldspar (called *kaolin*), silica, and a small proportion of lime, the ingredients being carefully selected, and thoroughly ground and incorporated. When moulded into the proper form, the articles are dried and subjected to a high heat in a furnace, in which state the

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alum? 776. Uses of alum? 777. How does it illustrate isomorphism? 778. Give the composition and origin of clay. What quality adapts it for pottery. Why must the ware be glazed? 779. What is porcelain? Describe its manufacture. How is it colored? 780. How is common red pottery ware made? Why is it ob-

ware is called *biscuit*. They are then glazed by dipping them into a solution of powdered quartz and feldspar, which, when heated, fuses into the ware, giving it a vitreous coating which adds to its compactness and strength. The partial fusion of the materials gives porcelain the beautiful semi-transparency which distinguishes it from earthen ware. In coloring porcelain, the patterns are printed on paper which is applied to the biscuit while the color is still moist. When the color is absorbed, the porcelain is subjected to another baking, which fixes the tint. In the finer kinds of porcelain the colors are mixed with a fusible glaze, and applied with a hair pencil.

**780. Common Red Pottery Ware** owes its color to oxide of iron, and is glazed with a preparation of clay and oxide of lead. Vessels thus coated are objectionable for domestic use, as the lead glaze is sometimes dissolved by acids, producing poisonous effects. Bricks are unglazed. *Stone ware* is a coarse kind of porcelain glazed with salt. Fire bricks, muffles, and Hessian crucibles are made of a pure, infusible clay, containing a large amount of silica. The beautiful blue pigment ultramarine is a silicate of alumina, supposed to be colored with hyposulphite of soda and sulphide of sodium.

## § II. *Iron and its Compounds.*

### IRON.

*Sym. Fe.* (*Ferrum.*) *Equiv.* 28. *Sp. Gr.* 7.8.

**781.** Were we to seek for that circumstance which might best illustrate the peculiarities of ancient and modern civilization, we should perhaps find it in the history of this metal. The ancients, imbued with a martial spirit and passion for conquest, made iron the symbol of war, and gave it the emblem of Mars. And if it were required also to symbolize the pacific tendencies of modern society, its triumphs of industry and victories of mind over matter, its artistic achievements and scientific discoveries, we should naturally employ the same metal *iron*. As gold and jewels have long been the type of barbaric and empty pomp, so iron may now be well regarded as the emblem of beneficent and intelligent industry.

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jectionable for domestic purposes? What is stoneware? Firebrick? What ultramarine? 781. What is said of the relations of iron to civilization? 782. Men-

**782. Uses of Iron.**—Iron in some of its innumerable forms ministers to the benefit of all. The implements of the miner, the farmer, the carpenter, the mason, the smith, the shipwright, are made *of* iron and *with* iron. Roads of iron, travelled by iron steeds, which drag whole townships after them and outstrip the birds, have become our commonest highways. Ponderous iron ships are afloat upon the ocean, with massive iron engines to propel them; iron anchors to stay them in storms; iron needles to guide them, and springs of iron in chronometers by which they measure the time. Ink, pens, and printing presses by which knowledge is scattered over the world, are alike made of iron. It warms us in our apartments; relieves our jolts in the carriage; ministers to our ailments in the chalybeate waters or the medicinal dose; it gives variety of color to rocks and soils of the earth, nourishment to vegetation, and vigor to the blood of man. Such are the powers of a substance which chemists extract from an otherwise worthless stone.

**783.** Iron occurs in nature almost universally in a state of combination. The mineral masses which it forms with oxygen, carbon, sulphur, and the metals, and from which it is extracted, are called its *ores*. Of these there are no less than 19 varieties, 8 or 9 of which are worked for their iron alone, while several of the others yield substances of great value in the arts, such as sulphur, arsenic, chronium, &c.

**784. Ores of Iron.** *Magnetic iron ore*, $FeO, Fe_2O_3$ (*Loadstone*).—This is a combination of the protoxide and sesquioxide, and is one of the richest ores of iron, containing 72 per cent. of the metal and 28 of oxygen. It is strongly magnetic, of a grayish color, and when rubbed gives a black powder. This ore is very widely diffused, and furnishes iron of the best quality. It affords the superior iron obtained from Russia, Germany, and Sweden.

**785. Specular, or Red Iron Ore** is a sesquioxide, $Fe_2O_3$, very hard and sometimes presenting the appearance of polished steel. When coarse, it is of a brown color, but its powder is always red, a quality which distinguishes it from the magnetic oxide. This oxide contains 63 per cent. of iron to 37 of oxygen. It exists in

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tion some of the uses of iron. 783. How does it occur? What is said of its ores? 784. What is the composition of magnetic ore? What its quality? Its properties? 785. What is specular iron ore? How distinguished from the magnetic? When are red clays called ores? 786. What is red hematite? Brown hematite?

all the red clays, which, when they yield 25 per cent. of the metal, are termed ores.

**786. Red Hematite**, $Fe\ O_3$, is another anhydrous sesquioxide, found in large quantities and considerably worked. *Brown Hematite*, or hydrated peroxide of iron, $2Fe_2O_3 3HO$, is very abundant throughout the world and particularly in the United States. It affords a yellow powder, and is not attracted by the magnet. It contains about 86 per cent. of peroxide of iron to 17 per cent. of water.

**787. Carbonate of Iron** (*Spathic Iron*, *Steel Ore*).—This contains 63 per cent. of oxide of iron, 34 per cent. of carbonic acid, and a small quantity of lime, magnesia, and manganese. A variety of steel is made directly from this ore. It is the source of the cheap German steel.

**788. Clay Ironstone** is another carbonate of iron, having a yellowish-brown color, and is one of the chief sources of the iron of commerce. It occurs among the coal measures mixed with clay, and contains about 37 per cent. of iron. There are several other ores worked for their iron to some extent, but those mentioned are the most important.

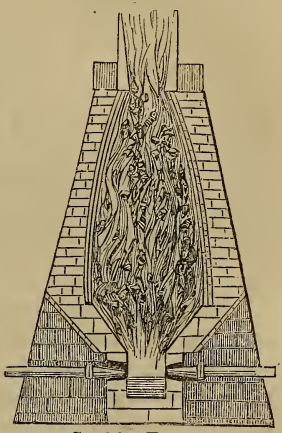
**789. Bisulphide of Iron,** $FeS_2$, is the *pyrites* of mineralogists, so named because it was used in firelocks to strike fire with steel before the introduction of gun flints. It occurs in large quantities and under several different forms. Yellow pyrites, when in the form of minute brilliant scales, is sometimes mistaken for gold (*fool's gold*). It is tested at once by the sulphurous odor it emits when heated. This variety contains 47 per cent. of iron to 53 of sulphur. Pyrites is chiefly prized as a source of copperas, alum, Spanish brown, sulphur, and sulphuric acid. It is never worked for its iron.

**790. Obtaining the Metal.**—The process of separating iron from its ores is called *reducing* or *reviving* it, and the ores are said to be *smelted*. The operation is conducted in tall chimney-like structures, termed blast furnaces. They are constructed of stone, and lined with the most refractory fire brick, having the form seen in Fig. 259. The top or mouth of the furnace serves for charging it, and for the escape of smoke; it is both door and

787. What is the composition of steel ore? 788. Of clay iron stone? What other ores are mentioned? 789. What is bisulphide of iron? What is fool's gold? Use of pyrites? 790. How is the operation of smelting performed? Describe the blast

chimney. The tubes or *tuyere pipes* at the bottom serve to supply the air, which is forced in by means of immense blowing cylinders driven by water or steam power. The amount of air thus forced through some large furnaces, exceeds 12,000 cubic feet per minute. Formerly the air was used at the ordinary temperature (*cold blast*), but within a few years an immense improvement has been effected by heating the air before it enters the furnace (*hot blast*).

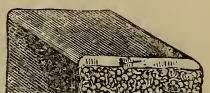
Fig. 259.



Smelting Furnace.

**791.** In some cases the materials are drawn up an inclined plane to the mouth of the shaft by the same engine that impels the blast mechanism. The furnace is supplied with ore, coal, and limestone broken into small fragments. When the heat is sufficiently intense the carbon of the fuel deoxidizes the iron, and carbonic acid is also expelled from the lime, leaving it caustic. Sand and clay, in greater or less quantities, now remain combined with the iron. The lime, acting as a flux, unites with these, forming the *slag* or *scoria*, a crude semi-vitreous product. The melted iron, falling to the bottom of the furnace, accumulates and is drawn off by taking out a *tap* or *plug*. It is allowed to run into a bed of sand, containing straight channels and furrows running at right angles. The former are called by the workmen the *sow*, and the latter the *pigs;* hence the term *pig-iron*. As the contents of the furnace are removed from below, crude ore is constantly supplied from above, and the operation goes on day and night uninterruptedly for a course of years, or until the fabric demands repair.

Fig. 260.



Texture of Cast Iron.

**792.** The product of the smelting furnace is *cast iron*. This

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furnace? 791. What are the changes occurring in the furnace? 792. What are the properties of cast iron? To what due? What is wrought iron? 793. State the

has a granular texture, Fig. 260, and is so brittle that it cannot be forged, but may be remelted and cast into moulds. It expands when first poured into the mould, so as to copy it perfectly, but subsequently contracts. The expansion is caused by the particles assuming a crystalline arrangement while consolidating; the contraction by the cooling of the metallic mass when solidified. These properties of brittleness and easy fusibility are due to the presence of a considerable quantity of carbon and other impurities, the removal of which converts it into *wrought iron.*

**793. Physical Properties of Iron.**—Iron is of a grayish white color, and when polished has a perfect lustre. The various conditions under which it appears in the arts are due to the presence or absence of certain other substances, such as carbon, silicon, sulphur, phosphorus, manganese, and arsenic. In the absence of these substances, iron is so malleable that books have been made of it with leaves as thin as paper, and so ductile that it may be drawn out into wires as thin as a hair. Its most useful quality, however, is its superior tenacity, or power of resisting strain; no other metal being equal to it in this respect. Hence the value of iron in the manufacture of cannons and mortars, where the immense expansive force of gunpowder is to be resisted, and in the making of wire cables for suspension bridges. So great is its tenacity that an iron wire 0.075 of an inch in diameter is capable of supporting a weight of 449 pounds.

**794. Passive Iron.**—In its ordinary condition iron oxidizes rapidly in the air, and dissolves in nitric acid. But under several circumstances it assumes different and peculiar chemical relations. If momentarily immersed in a strong mixture of nitric and sulphuric acids it retains its metallic lustre, but has lost the power of either being oxidized in the air or of dissolving in nitric acid; it has become *passive*, or assumed an allotropic form.

**795. Wrought Iron.**—The operation of separating carbon and other foreign substances from cast iron is usually conducted in reverberatory furnaces. In this process the fire is not mingled with the metal, as in the case of smelting, but the material is melted by causing the flame to impinge upon it on its way through the furnace, as shown in Fig. 261. A work-

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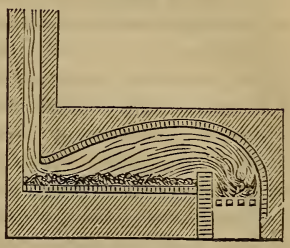
physical properties of iron. 794. What is passive iron? 795. How is wrought iron obtained? 796. How may the quality be still improved? How is wrought

man, with a long, oar-shaped implement of iron, stirs (*puddles*) the melted mass until the carbon and other impurities of a like nature are burned away, and the metal becomes thick and pasty. This is called *puddling*. The puddler then rolls up from the mass a ball of about 75 lbs. weight, which he transfers to the tilting or trip hammer, where it is beaten by heavy blows into a crude bar. By this operation the liquid impurities, consisting chiefly of silica and alumina, are squeezed out, as water is expelled from a compressed sponge.

Fig. 261.

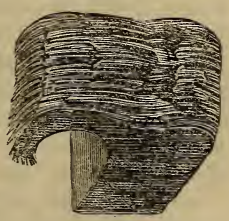


Puddling Furnace.

**796.** The metal, still hot, is then passed between grooved cylinders, where it is rolled out into *bar iron*. The quality of metal is greatly improved when these bars are broken up, bound together, reheated to the welding point, and again passed through the rolling mill. This latter operation is often repeated several times, and is known as *piling* or *fagoting*. Wrought iron may be produced directly from the magnetic ore. The process is conducted on what is termed a *catalan forge*, or *bloomary*, a structure much resembling a blacksmith's forge, on a large scale. The operation consists in the reduction of the oxide by means of charcoal, after which the iron obtained is put through the same course of hammering and rolling as if it came from the puddling furnace.

**797.** Wrought iron has a fibrous texture, and rough, hackly fracture, Fig. 262. It is said to lose this tough, fibrous character by the effect of constant jarring, and to become crystalline. It usually contains a small quantity of carbon, which hardens the iron without affecting its other properties, but if the amount exceeds $\frac{1}{2}$ per cent., it renders the iron *cold-short*, that is, brittle and liable to snap asunder when cold. The presence of sulphur, even in so small a proportion as $\frac{1}{10,000}$, unfits the iron for being worked at a

Fig. 262.



Texture of Wrought Iron.

iron made from the ore? 797. What is the effect of carbon in wrought iron? Of sulphur? 798. What is welding? What precaution is necessary? What metals

red heat, as it is liable to split when hammered; it is then said to be *hot-short*.

793. **Welding of Iron.**—When wrought iron is heated to whiteness, it becomes soft, pasty, and adhesive, and two pieces in this condition may be incorporated, or hammered into one. This is called *welding*. During the heating a film of oxide is formed upon the surface of the metal, which would obstruct the ready cohesion of the separate masses. To prevent this, the smith sprinkles a little sand upon the hot iron, which combines with the oxide, forming a fusible silicate of iron, which is easily forced out by pressure, leaving clean surfaces that unite without difficulty. This important quality is possessed only by iron, platinum, and sodium. All the other metals pass suddenly from the solid to the liquid state at their respective melting points.

799. **Steel.**—This remarkable modification of iron is a compound of the metal with about one and a half per cent. of carbon. It is made by imbedding bars of the best wrought iron in powdered charcoal, in boxes or sand-furnaces, which exclude the air, and heating it intensely for a week or ten days. The chemical changes are obscure; probably carbonic oxide penetrates the heated metal, is decomposed, surrenders part of its carbon and escapes as carbonic acid. The steel when withdrawn has a peculiar rough, blistered appearance, and is hence known as *blistered steel*. This method of making steel is called the process of *cementation*.

800. In its properties steel combines the fusibility of cast iron with the malleability of bar iron. Its value for cutting instruments, springs, &c., depends upon its quality of being *tempered*. When heated to redness and suddenly quenched in cold water, it becomes so hard as to scratch glass. If again heated and cooled slowly, it becomes as soft as ordinary iron, and between these two conditions any required degree of hardness can be obtained. As the metal declines in temperature, the thin film of oxide upon its surface constantly changes its color. The workmen are guided by these tints. Thus a straw color indicates the degree of hardness for razors; a deep blue for sword blades, saws and watch springs. Steel receives a higher polish than iron and has less tendency to

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possess this property? 799. What is steel? How is it made? What is blistered steel? 800. Upon what does its value for cutting instruments depend? How is this

rust. Nitric acid placed upon steel corrodes it, and leaves the carbon as a dark gray stain; hence it is often used for writing and ornamental shading upon this metal.

**801. Oxides of Iron.**—Iron has a strong affinity for oxygen, with which it forms four well marked compounds, viz.: the protoxide $FeO$; the sesquioxide or peroxide $Fe_2O_3$; the magnetic oxide, supposed to be a combination of the two preceding, and having the formula $FeO, Fe_2O_3$, or $Fe_3O_4$, and ferric acid $FeO_3$. The first three are the most abundant, existing in stones, rocks, and soils, and imparting to them their red and yellow colors.

**802. The Protoxide** is not found in the separate state, as it rapidly absorbs oxygen, and passes into the sesquioxide. It is the basis of all the green salts of iron, and in a state of combination is widely diffused, existing chiefly in those rocks having a greenish or dark tint. The iron in chalybeate waters usually rises to the surface as a protoxide, and there absorbing oxygen from the air, the peroxide is formed, and sinks to the bottom as an insoluble, reddish sediment.

**803. The Anhydrous Sesquioxide** is known in commerce under the name of *colcathar* or *rouge*, and is extensively employed in polishing glass, jewelry, &c. It is also used as a pigment. The hydrated sesquioxide, associated with alumina, forms the *umbers* and *ochres* so much used as pigments.

**804. Magnetic Oxide.**—The black scale, which forms on iron when heated, consists of *magnetic oxide*. This is also the result of the combustion of iron in oxygen gas. It is the only oxide possessing magnetic properties. *Ferric acid* is a very unstable compound, and is of little account.

**805. Protosulphate of Iron** (*Green Vitriol, Copperas*).—This salt, as its name indicates, is a compound of the protoxide of iron with sulphuric acid. It is largely manufactured at Stafford, Conn., from iron pyrites, which furnishes by oxidation both the acid and the base. It is used in dyeing, for making ink and Prussian blue, and in medicine. It often exists in soils to a pernicious extent, but is decomposed by lime; gypsum being formed.

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determined? What is the effect of nitric acid upon steel? 801. What is the composition of the oxides of iron? 802. Give an account of the protoxide. 803. Of the anhydrous sesquioxide. Of the hydrated. 804. What is the magnetic oxide? 805. What

## § III. *Manganese, Nickel, Zinc, Cobalt, Cadmium, Tin.*

### MANGANESE.

*Sym. Mn. Equiv.* 27.48. *Sp. Gr.* 8.

**806. Manganese** is a hard, brittle metal of a grayish-white color. It never occurs pure in nature, but its oxides are found combined with many ores of iron, a metal which it resembles in many of its properties. Manganese is obtained by making its oxide into a paste with oil and lampblack, and heating it to whiteness in a covered crucible. It rapidly oxidizes when exposed to the air, and is best preserved in naphtha.

**807.** It forms no less than seven different compounds with oxygen. Its oxides are diffused in small quantities through most soils, and traces of them may be detected in the ashes of nearly all plants. *Protoxide of manganese* is of a pale green color and is a powerful base, giving rise to rose-colored salts. The *peroxide* or *black oxide*, $MnO_2$, is employed as a cheap method of procuring oxygen on a large scale, and for the manufacture of chlorine and steel. It is also used under the name of *glassmaker's soap* to destroy the green tinge given to glass by protoxide of iron and to oxidize carbonaceous impurities. If added to glass in large quantities, it gives it a purple color.

### NICKEL.

*Sym. Ni. Equiv.* 29.5. *Sp. Gr.* 8.8.

**808.** This is a brilliant white metal, somewhat malleable and ductile. At ordinary temperatures it is magnetic, but if heated above 630° it loses this property, acquiring it again, however, on cooling. It is used principally in the formation of alloys. Nickel forms oxides, but they are of little interest.

### COBALT.

*Sym. Co. Equiv.* 29.5. *Sp. Gr.* 8.9.

**809. Cobalt** generally occurs in combination with arsenic or nickel, though it is sometimes found native in meteoric masses.

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the protosulphate? 806. What is manganese? How is it obtained? How kept? 807. What is said of its compounds with oxygen? What of the protoxide? The peroxide? Its uses? 808. What are the properties of nickel? 809. What is

When obtained pure it is a reddish-white, hard, brittle, strongly magnetic metal. It forms two oxides; the protoxide, CoO, and the sesquioxide, $Co_2O_3$. The protoxide is a grayish powder, which, when fused with glass, imparts to it a beautiful blue color. *Smalt* is a glass, colored blue by oxide of cobalt and then reduced to an impalpable powder. It is used for coloring on glass, paper, &c. *Zaffre*, used to impart a blue color to ordinary earthen ware, is an impure oxide of cobalt.

**810. Chloride of Cobalt** forms a pink solution which turns blue when dried. This solution is used as a sympathetic ink, the characters written with it being so pale as to be invisible till warmed, when they appear blue. On cooling they absorb moisture and again disappear.

## ZINC.

*Sym. Zn. Equiv.* 32.5. *Sp. Gr.* 7.

**811. Zinc** is a brilliant, bluish-white metal, found abundantly in nature in combination with sulphur as *zinc-blende*, and with oxygen and carbonic acid as *calamine*. It also exists in great quantities as a red oxide in New Jersey. At common temperatures it is brittle, but when heated from 212° to 300° it may be rolled out into thin sheets, and retains its malleability when cold. At 400° it again becomes quite brittle; at 770° it melts, and when exposed to air takes fire, burning with a whitish-green flame and forming oxide of zinc. Zinc soon tarnishes in a moist atmosphere, forming a thin film of oxide, which resists further change. This property renders it useful for a variety of purposes, such as for gas pipes, gutters, roofing, and for galvanizing iron, thus preventing it from oxidation. It is also used in the preparation of hydrogen gas.

**812. Oxide of Zinc,** ZnO.—This is formed when zinc is burned with free access of air. It is a fine, white powder, and is the only oxide of zinc known. It is used largely as a paint.

**813. Sulphate of Zinc,** $ZnO, SO_3$ (*White Vitriol*).—This may be prepared either by roasting the sulphide, or by the action of sulphuric acid on the pure metal. It strongly resembles the sul-

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cobalt? Mention its compounds. State their uses. 810. What is chloride of cobalt? 811. What is zinc? How does it occur? State its properties. Its uses. 812. What is oxide of zinc? For what used? 813. How is sulphate of zinc ob-

phate of magnesia, and is used in medicine and in certain operations of calico printing.

### CADMIUM.

*Sym. Cd. Equiv.* 56. *Sp. Gr.* 8.6.

**814. Cadmium** is usually found associated with zinc. It is a white, volatile metal, somewhat malleable and ductile, and so soft as to leave a mark when rubbed upon paper. It forms an oxide, CdO, which may be obtained by burning the metal in air.

### TIN.

*Sym. Sn.* (*Stannum*). *Equiv.* 59. *Sp. Gr.* 7.8.

**815. Tin** is a brilliant, silver-white metal, which occurs most abundantly in Cornwall, England. It has been found in this country only at Jackson, N. H., and in small quantities. It is softer than gold, slightly ductile and very malleable, common tin foil being often not more than $\frac{1}{1000}$ of an inch in thickness. It melts at 442°. The peculiar crackling sound given by tin when bent, is due to a disturbance of its crystalline structure. Owing to its weak affinity for oxygen it tarnishes but slightly on exposure to the air or moisture, and is therefore very valuable for domestic utensils. This property also renders it useful for coating other metals to prevent them from oxidizing. Sheet iron coated with tin, with which it forms an alloy, constitutes common tin ware.

**816.** There are two well marked oxides of tin; the protoxide, SnO, and the binoxide, $SnO_2$. The protoxide acts as a base, but the binoxide, when combined with water, has distinct acid properties. Tin forms several very important alloys.

## CHAPTER XVI.

### METALS WHICH DO NOT DECOMPOSE WATER.

| | | |
|---|---|---|
| Chromium, | Columbium, | Gold, |
| Arsenic, | Tantalum, | Platinum, |
| Antimony, | Molybdenum, | Palladium, |
| Bismuth, | Tungsten, | Rhodium, |
| Copper, | Vanadium, | Ruthenium, |
| Lead, | Uranium, | Osmium, |
| Thallium, | Mercury, | Iridium. |
| Titanium, | Silver, | |

tained? 814. What is cadmium? 815. What are the sources of tin? Its proper-

## § I. *Chromium, Arsenic.*

### CHROMIUM.

*Sym. Cr. Equiv.* 26.3. *Sp. Gr.* 6.8.

**817. Chromium** is an exceedingly hard, brittle, grayish-white metal, and derives its name (*chroma, color*) from the beautiful color of many of its compounds. It is rarely met with, but is abundant in some localities. It usually occurs as a sesquioxide in combination with protoxide of iron, forming the mineral chrome iron-stone. It also occurs in union with oxygen and lead as chromate of lead.

**818.** Chromium has a strong attraction for oxygen, with which it forms several compounds. Among these the most important is the *sesquioxide* $Cr_2O_3$, and *chromic acid* $CrO_3$, both of which resemble the corresponding compounds of iron. The sesquioxide is a feeble base, isomorphous with the sesquioxide of iron and with alumina; it may therefore replace either of these in combination. The hydrated sesquioxide is of a pale green color, but by ignition loses its water, and becomes of a dark green. This oxide is used in coloring glass and porcelain, and is the coloring ingredient of green-stone, the emerald, &c.

**819. Chromic Acid** is interesting as being one of the constituents of chromate of lead, the beautiful yellow pigment known as *chrome yellow*. The color of the ruby is due to the presence of this acid. In union with potash it forms the bichromate, a salt considerably used in the laboratory and in dyeing, calico printing, &c.

### ARSENIC.

*Sym. As. Equiv.* 75. *Sp. Gr.* 5.8.

**820.** Arsenic is a crystalline, brittle metal, of a steel-gray color and bright metallic lustre. It is found alloyed with iron, nickel, cobalt, copper, tin, lead, &c.; but the chief source of the arsenic of the shops is *mispickel*, a double sulphide of arsenic and iron. The coarse, gray powder, sold under the name of fly poison,

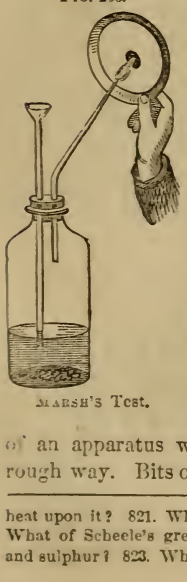
ties? What is tin ware? 816. What compounds of tin are mentioned? 817. What is chromium? Why so named? 818. What are the properties of chromium and its compounds? 819. In what does the interest of chromic acid consist? 820. State the properties of arsenic. What are its sources? What is fly poison? Effect of

cobalt, &c., consists simply of metallic arsenic. When arsenic is heated in a close vessel to 356°, it volatilizes without fusion, giving off a dense, colorless vapor, having the peculiar odor of garlic. If heated in the open air it takes fire, burning with a blue flame, and uniting with oxygen to form arsenious acid.

821. **Arsenic and Oxygen.**—There are but two of these compounds: arsenious acid, $AsO_3$, and arsenic acid, $AsO_5$. The first constitutes the common white arsenic of the shops, the well-known *ratsbane*. It is soluble in about ten parts of hot water, the solution having a slightly sweetish taste and acid reaction. It also dissolves readily in hot chlorohydric acid, and in solutions of the alkalies. Combined with copper, it forms the beautiful pigment known as *Scheele's green*, which is used extensively in coloring paper hangings. Owing to its remarkable antiseptic power, it is used to preserve dried and stuffed specimens by collectors of objects of natural history. Its most effectual antidotes are the moist hydrated oxide of iron and caustic magnesia.

822. **Arsenic Acid** is formed by oxidizing arsenious acid by means of nitric acid. It has strongly acid properties, decomposing the carbonates with effervescence, and readily forming salts with the alkalies. Sulphur forms no less than five compounds with arsenic, of which the most important are *realger* or red orpiment, a bisulphide, and yellow orpiment, or *king's yellow*, a tersulphide.

Fig. 263.



Marsh's Test.

823. **Arseniuretted Hydrogen,** $H_3As$.—This gas may be formed by decomposing an alloy of arsenic and iron with dilute sulphuric acid, or by introducing a solution of arsenic into a flask in which hydrogen is being evolved. It burns with a bluish-white flame, is highly poisonous and of a disgusting odor.

824. In Marsh's test hydrogen is generated, and if arsenic be present arseniuretted hydrogen is formed. Fig. 263 shows the form of an apparatus which answers very well for this purpose in a rough way. Bits of zinc and a little water are placed in the vessel,

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heat upon it? 821. What are the composition and properties of arsenious acid? What of Scheele's green? 822. Of arsenic acid? Of the compounds of arsenic and sulphur? 823. What is arsenide of hydrogen? 824. What is Marsh's test for

which is provided with a cork through which a tube is inserted. Sulphuric acid is now poured in through the funnel tube, and the evolution of hydrogen commences. After the air has been completely expelled from the flask, the gas may be lighted at the jet. If the solution containing arsenic be now poured in through the funnel tube, the color of the flame immediately changes, and a cold, white surface, held so as to cut the flame in half, is stained with a black or brown spot by the deposition of metallic arsenic. Antimony produces a similar effect, but a solution of hypochlorite of lime or soda dissolves the arsenical stain, leaving that made by antimony unchanged. This is a very delicate test, but great care should be taken that the sulphuric acid and zinc do not contain any previous traces of arsenic.

## § II. *Antimony—Bismuth—Copper—Lead.*

### ANTIMONY.

*Sym. Sb.* (*Stibium*). *Equiv.* 129. *Sp. Gr.* 6.7.

**825.** Antimony is a brilliant, brittle, bluish white crystalline metal, usually found in combination with sulphur, though it often occurs alloyed with other metals, and sometimes exists native. The principal source of the metal is the native sulphide, from which it is separated by heating with iron filings, or carbonate of potash. These combine with the sulphur, setting the metal free.

**826. Oxides of Antimony.**—The teroxide, $SbO_3$, is the most important, as it furnishes the basis of the antimonial so much used in medicine. Antimonic acid, $SbO_5$, readily combines with bases to form salts, and even unites with the teroxide, forming antimoniate or antimony, or what is sometimes called antimonious acid.

### BISMUTH.

*Sym. Bi.* *Equiv.* $210_3$. *Sp. Gr.* 9.8.

**827. Bismuth** is a hard, brittle, reddish white metal, found both native and in combination. At a high temperature it is slightly volatile, and oxidizes rapidly. Its fusing point is 507°, but it forms alloys with other metals which melt below 212°. It forms two combinations with oxygen; the teroxide, $BiO_3$, and bis-

arsenic? 825. How is antimony found in nature? 826. What of its oxides? 827. What are the properties of bismuth? What of its oxides? 828. What

muthic acid, $BiO_5$. The latter is interesting only to the chemist; but the former, in combination with nitric acid and water, forms *pearl powder*, the popular cosmetic.

## COPPER.

*Sym. Cu.* (*Cuprum*). *Equiv.* 31.7. *Sp. Gr.* 8.9.

828. This well-known metal needs little description. It is tough, malleable, of a red color, and often found native in masses of great magnitude. Its ores are numerous and wide-spread. Among the most common of these is the red oxide of copper, CuO, and copper pyrites, a double sulphide of copper and iron. Copper is stiffened by hammering, and softened by heating and suddenly cooling in water; the reverse of the effect produced upon steel. In dry air it is hardly acted upon, but in a damp atmosphere it acquires a green crust of carbonate, familiarly known as *verdigris*.

829. Copper is an excellent conductor of heat and electricity, and is extensively used for telegraph wires. Being little affected by the air, it is better adapted for culinary and many other utensils than iron. Vegetable acids, however, dissolve it in the cold state; hence sauces containing vinegar, and preserved fruits or jellies should not be allowed to remain in copper vessels, as the salts produced are poisonous.

830. **Oxides of Copper.**—Copper forms several oxides of which the protoxide or black oxide, CuO, is the most important, as it constitutes the basis of most of the salts of copper. It is used in organic analysis as a source of oxygen, and in the manufacture of glass and porcelain to impart a green color.

831. **Sulphate of Copper,** $CuO, SO_3+5HO$ (*Blue Vitriol*).—This is used largely in dyeing and calico printing, and as a source of many of the pigments containing copper.

832. **Nitrate of Copper,** $CuO, NO_5 + 3HO$, is formed by dissolving copper in dilute nitric acid. It is a very corrosive, deliquescent salt, of a deep blue color, is easily decomposed, and crystallizes in prisms.

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are the most common ores of copper? How are its properties altered? What is verdigris? 829. For what is copper well adapted? What precaution is given? 830. What is said of the oxides of copper? 831. Of sulphate of copper? 832. Of

## LEAD.

*Sym. Pb.* (*Plumbum*). *Equiv.* 103.6. *Sp. Gr.* 11.44.

**833.** This useful and common metal occurs under various mineral forms, of which the most valuable is *galena*, a sulphide. Lead is a soft, blue metal, easily scratched by the nail, and leaving a stain when rubbed upon paper. It is highly malleable, but not very ductile. In the air a film of oxide rapidly forms on its surface, which protects it from further corrosion. It melts at about 612°, and on solidifying contracts to such an extent as to render it unfit for castings.

**834.** If lead is exposed to the combined action of pure water and air, an oxide of lead is formed on the exposed surface, which is dissolved by the water with which it is in contact. This solution of oxide of lead absorbs carbonic acid, forming a carbonate of the oxide of lead, an insoluble but highly poisonous compound. The presence of chlorides or nitrates assists this corroding action, while it is retarded by the sulphates, phosphates, or carbonates. Bicarbonate of lime, a salt found in many spring waters, also prevents this corrosion by depositing a coating on the exposed surface. In the use, therefore, of lead water pipes, it should be carefully ascertained whether the water to be conveyed contains foreign matters, which will prevent its action upon the metal.

**835. Oxides of Lead.**—There are four oxides of lead, the most important of which are the *protoxide* and *peroxide*. The *protoxide of lead*, *PbO*, forms the basis of the ordinary salts of this metal, and is the well-known powder called *litharge*. As it easily fuses, and readily dissolves silica, it is much used in glass-making and in glazing earthenware. The *peroxide of lead*, $PbO_2$, called *minium* or *red lead*, is consumed largely in the manufacture of flint glass.

**836. Carbonate of Lead,** $PbO,CO_2$ (*White Lead*).—This salt is found beautifully crystallized in nature, but it is largely manufactured as a paint. It is produced in several ways, but the following, which is known as the Dutch method, is considered the best. Thin sheets of lead, rolled up into loose scrolls, are placed in earthen pots with weak vinegar or acetic acid. Thousands of

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nitrate? 833. What is galena? Properties of lead? 834. What is the action of water upon lead? How may the operation be assisted, or retarded? In the use of lead pipes for water what should be determined? 835. What is said of the oxides of lead? What are the uses of litharge? What of minium? 836. What is car-

these pots, fitted with lead covers and closely packed, are then buried in spent tan bark. The acetic acid corrodes the metal, forming a superficial coating of acetate of lead. The carbonic acid set free by the decomposing vegetable matter, displaces the acetic acid, combining with the lead, and forming the carbonate. The acetic acid thus released, attacks more metal, which is again carbonized, and thus, with a small charge of vinegar, the operation is continued a long time, and a large quantity of lead changed. White lead is extensively adulterated with sulphate of baryta; it may be detected by adding nitric acid, which dissolves the lead, leaving the baryta as an insoluble residue.

**837. Thallium** is a metal recently discovered by means of spectrum analysis, and is found in pyrites and in native sulphur. It is of a brilliant white, soft, malleable, has a specific gravity of 11.9, and resembles lead. It forms compounds with oxygen, chlorine, iodine, bromine, sulphur, and phosphorus—its oxides having a decidedly alkaline reaction.

**838. Titanium, Columbium, Tantalum, Molybdenum, Tungsten, Vanadium,** and **Uranium,** are very rare metals, and comparatively unimportant. Titanium and uranium are somewhat used for coloring enamels and porcelain, and the salts of the latter possess considerable chemical interest.

## § III. *The Noble Metals—Mercury, Silver, Gold, Platinum, &c.*

### MERCURY.

*Sym.* Hg. (*Hydrargyrum*). *Equiv.* 100. *Sp. Gr.* 13.59.

**839.** Sulphide of mercury, or cinnabar, is the principal source of this metal, though it is sometimes found native and also combined with silver. It has a silver-white color, a brilliant lustre, and is a fluid at ordinary temperatures. It solidifies, when cooled to —39°, and is then soft and malleable, but if reduced to a much lower temperature, it becomes brittle. It boils at about 662°, and slowly volatilizes at all temperatures above 40°. Metallic mercury is used extensively in the manufacture of philosophical in-

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bonate of lead? How is it produced? How is it adulterated? Explain the mode of its detection? 837. What are the properties of thallium? 838. Of titanium and uranium? 839. In what state is mercury usually found? What are its proper-

struments, thermometers, barometers, and as an alloy with tin for coating the backs of mirrors. It is also used largely in the extraction of gold and silver by the process of amalgamation.

**340. Oxides of Mercury.**—There are two oxides of mercury. The first, the suboxide $Hg_2O$, is of little importance. The protoxide, HgO, commonly known as the *red oxide*, or *red precipitate*, may be formed by heating metallic mercury up to 600°, with free access of air. A still higher heat decomposes it, liberating the oxygen, and reducing the mercury to the metallic state. This oxide forms the basis of most of the salts of mercury, and furnishes a ready source of oxygen gas. It is the compound from which oxygen was first obtained by PRIESTLEY, and by which LAVOISIER proved the composition of air.

**341. Chlorides of Mercury.**—Two chlorides corresponding to the above-named oxides are known. The subchloride $Hg_2Cl$, familiarly known as *calomel*, is prepared by precipitating a solution of subnitrate of mercury with common salt. It is a yellowish-white, tasteless, insoluble powder, used extensively in medicine. The chloride HgCl, or *corrosive sublimate*, is formed by sublimation from a mixture of sulphate of the protoxide of mercury and common salt. Corrosive sublimate has a disagreeable, acrid, metallic taste, and is very poisonous. The proper antidote is white of egg, which forms with it an insoluble, inert compound.

**342. Sulphide of Mercury** (cinnabar) occurs in large beds at Almaden, in Spain, and is also found in extensive deposits in California. It is produced in considerable quantity by artificial means, and sold as a pigment under the name of *vermilion*.

## SILVER.

*Sym. Ag.* (*Argentum*). *Equiv.* 108. *Sp. Gr.* 10.5.

**343.** Silver is found both native and in combination. When native, it occurs in fibrous, or crystalline masses; and when combined with sulphur, it is usually associated with sulphides of lead, antimony, and copper. The principal mines of silver are those of Mexico and Peru.

**344. Preparation.**—Silver is obtained from the sulphuret by

ties? Its uses? 340. How many oxides of mercury are there? What is the effect of heat upon the red oxide? 341. What is the composition of calomel? Give its preparation. How is corrosive sublimate formed? What is the antidote? 342. What is vermilion? 343. What is the appearance of native silver? With

roasting the ore with common salt, which converts it into a chloride. It is then, together with water, iron scraps and mercury, put into casks, which are revolved on their axes. The iron removes the chlorine, and the mercury amalgamates with the silver, from which it is afterward freed by distillation.

845. Silver is separated from its combination with lead by melting the alloy and letting it slowly cool, when the lead solidifies in crystals, leaving the silver nearly pure. It is further refined by the process of *cupellation;* a *cupel* being a shallow, porous vessel, made of bone ashes. When it is melted with access of air, the lead oxidizes; the oxide, or litharge melts, and being absorbed by the cupel, leaves the silver pure.

846. **Properties.**—Silver is the whitest of the metals, with a bright, metallic lustre. It is very malleable, ductile and tenacious. It may be extended into leaves not exceeding $\frac{1}{10}\frac{1}{000}$ of an inch in thickness, and 1 grain may be drawn out into 400 feet of wire. Silver does not oxidize in the air at any temperature, but absorbs oxygen when melted, holding it mechanically and giving it off on solidifying. It is a good conductor of heat and electricity, and its polished surface is one of the best reflectors of light. Silver is chiefly consumed in coinage and in the manufacture of silver plate. Being too soft for these purposes when pure, it is usually alloyed with about $\frac{1}{10}$ its weight of copper, which gives it the requisite hardness.

847. **Oxides of Silver.**—These can be formed only by indirect means. There are three of them, but the protoxide, AgO, is the only one which claims our attention. It may be made by dissolving silver in nitric acid, forming nitrate of silver, and then precipitating it with potash. It is a dark brown or black powder, which forms the basis of the most important salts of silver. It is decomposed below a red heat, oxygen being liberated, and the silver reduced to the metallic state.

848. **Nitrate of Silver,** $AgO,NO_5$.—This, the most interesting salt of silver, may be obtained by dissolving metallic silver in nitric acid; colorless, anhydrous crystals being formed, which are readily soluble in an equal weight of cold water. These crystals,

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what is it associated in combination? 844. How is it obtained from the sulphuret? 845. How from its combination with lead? 846. What are the properties of silver? Its uses? Why is it alloyed? 847. What is said of the oxides of silver? 848. How is nitrate of silver obtained? For what used? How may the stain be removed?

when melted and cast into small sticks, form the lunar caustic of surgery. Nitrate of silver stains organic matter black under the action of light. Advantage is taken of this property in making indelible ink and hair dye. A solution of cyanide of potassium removes the stain thus produced.

**849. Chloride of Silver,** AgCl, is occasionally found native in mines, and is called *horn silver*, from its tough, horny texture. It may be prepared artificially by adding a solution of common salt to a solution of nitrate of silver, and appears as a white powder which darkens in color on exposure to the air.

## GOLD.

*Sym. Au.* (*Aurum*). *Equiv.* 196.4. *Sp. Gr.* 19.34.

**850.** This is one of the most widely diffused of the metals and generally occurs in minute grains, though sometimes in masses weighing many pounds. In 1851 a lump weighing 106 pounds was found in Australia, imbedded in a matrix of quartz. It sometimes occurs in crystalline form, as shown in Fig. 264.

Fig. 264.

Crystal of Gold.

**851. Properties.**—Gold is a beautiful yellow metal, with a brilliant lustre and high specific gravity. It is the most malleable of metals, is exceedingly ductile, and when pure is nearly as soft as lead. It fuses at 2016°, and does not oxidize in the air at any temperature. Gold is dissolved by selenic acid, nascent cyanogen, and any solution that liberates chlorine; but its usual solvent is aqua regia. Like silver, it is too soft for the purposes of coinage and jewelry when pure; the required hardness being imparted by alloying it with $\frac{1}{10}$ of its weight of copper. This alloy forms the standard gold for coin in this country.

**852.** *Carat* is a term used to designate one of the parts or units of a certain number which is taken as the standard of pure gold. In the United States the number is 24, therefore pure gold is said to be 24 carats fine. If it contain 6 parts of alloy, it is 18 carats fine, and so on. *Assaying* is the determination of the amount of pure metal in an alloy, or specimen of bullion.

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849. How is chloride of silver produced? 850. What is said of the occurrence of gold? 851. The properties of gold? 852. What is meant by the term carat? What

**853. Preparation.**—Gold is separated from all its ores except silver by amalgamation with mercury. It is obtained from silver by boiling it in nitric acid which dissolves out the silver, leaving the gold pure. In this operation, in order to prevent the silver from being mechanically protected from the action of the acid, it is necessary that there should be three times as much silver as gold. As the gold constitutes only one quarter of the mass, the process is known as *quartation*.

**854.** Gold forms compounds with oxygen, sulphur, chlorine, bromine, iodine, &c., but they are not of sufficient interest to require mention.

## PLATINUM.

*Sym. Pl. Equiv.* 98.6. *Sp. Gr.* 21.5.

**855.** *Platinum* is a rare metal, always found native, and usually associated with palladium, rhodium, and iridium. It also occurs alloyed with gold, copper, iron, and lead. Its chief sources are the mines of Mexico, Brazil, and the Ural Mountains.

**856. Properties.**—Platinum is of a grayish-white color, and closely resembles silver in appearance. When pure it scarcely yields in malleability to gold and silver; is very ductile, and takes a good polish. But the qualities which render it so useful, and in some cases indispensable to the chemist, are its extreme difficulty of fusion (being unaffected by any furnace heat), and the perfect manner with which it resists the action of almost all acids. It does not oxidize in the air at any temperature, and is not acted upon by simple acids. It is slowly dissolved by aqua regia.

**857.** We have already alluded to the power possessed by *spongy platinum* of condensing gases and causing the union of oxygen and hydrogen. *Platinum black* is a preparation of the metal in a still more minute state of subdivision, and has the property of effecting chemical changes more energetically than platinum sponge. It may be produced by electrolyzing a dilute solution of the metal.

**858.** With the exception of the bichloride, the compounds of platinum are unimportant. The bichloride of platinum is useful to the chemist as furnishing an excellent test for potash, which it

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is assaying? 853. Explain the preparation of gold? 854. What other compounds of gold are mentioned? 855. How does platinum occur? What are its chief sources? 856. Its properties? Why do chemists prize it? 857. What is platinum

precipitates from a neutral or acid solution as a double chloride of potassium and platinum.

859. The remaining metals of this group, Palladium, Rhodium, Ruthenium, Osmium, and Iridium are rare and generally found associated with platinum, which they resemble both in appearance and properties.

## CHAPTER XVII.

### SEQUEL TO THE METALLIC ELEMENTS.

### § I. *Alloys.*

860. **Compounds of the Metals with each other.**—Metals combine with metals to form alloys, an important class of bodies, as each compound thus produced may be looked upon for many purposes as a new metal. These unions sometimes take place in equivalent proportions, but generally this is not the case.

861. Yet the properties of alloys cannot be anticipated. Slight variations in the proportions of the metals produce great changes in the products. Alloys are always more fusible than the most infusible element of which they are composed, and often more so than any of the ingredients. Bismuth melts at 476°, lead at 600°, and tin at 442°; but by combining them in the proportions of 5 parts bismuth, 2 lead, and 3 tin, Sir Isaac Newton produced a fusible metal which melts below 212°.

862. A metal of low fusibility, when melted in contact with one of high fusibility, causes the latter also to melt, thus acting as a *flux*. This principle is employed in *soldering*, or the joining two metals by means of a third. Pieces of gold are soldered together with an alloy of gold and silver; articles of silver with an alloy of silver and copper; copper with an alloy of copper and zinc (*hard solder*).

863. **Brass** is an alloy of copper and zinc; 4 parts of the former to 3 of the latter. An increased proportion of zinc gives *pinchbeck*, *Dutch gold*. German silver is an alloy of copper, zinc,

black? 858. Bichloride of platinum? 859. What is said of the remaining metals of this group? 860. What are alloys? What is the character of these compounds? 861. What is said of the properties of alloys? Give examples. 862. What is the

and nickel. *Bronze* consists of 90 parts copper to 10 of tin; bell metal and gong metal of 80 parts copper to 20 of tin.

**864. Type Metal** consists of 3 parts lead to 1 of antimony; *britannia* of 100 parts tin, 8 of antimony, 2 of bismuth, and 2 of copper. The speculum of Lord Rosse's telescope is composed of 126.4 of copper to 58.9 of tin. Alloys which contain mercury are called *amalgams*. An amalgam of tin is used for silvering the backs of mirrors; and an amalgam of tin and zinc for exciting electrical machines.

**865. Alloys of Aluminum.**—These promise to become very important as the metal grows cheaper: 10 parts of aluminum and 5 of copper form a very hard alloy, exactly resembling gold, and almost as exempt from liability to tarnish. An alloy of 3 parts iron to 1 of aluminum does not oxidize in a moist atmosphere, and 1 part aluminum to 9 parts copper, produces an alloy harder than bronze and whiter than copper.

**866. Alloys of Coin.**—Gold and silver when pure are so soft that if coins were struck from them, they would be injured by wear; hence they are alloyed to make them harder. The standard gold of the United States coinage consists of 9 parts of pure gold to 1 part of alloy. As copper would darken the color of the gold, the alloy consists of 9 parts of copper to 1 part of silver; thus 1,000 ounces of gold coin would contain 900 of pure gold, 90 of copper, and 10 of silver. The English alloy of gold is $\frac{1}{12}$ or 2 carats; 24 carats being pure gold. The silver coin of the United States is $\frac{9}{10}$ silver and $\frac{1}{10}$ copper; and the new cents 88 parts copper to 12 parts nickel.

## § II. *Chemistry of Photography.*

**867.** Reference was made to the subject of *Photography* when speaking of the chemical action of light; some further explanations will be suitable in this place.

**868. History.**—That the salts of silver are blackened by exposure to light was known to the alchemists. Scheele, in the last century, discovered that this effect takes place most energetically in the violet region of the spectrum. Ritter, in 1801, discovered the independent nature of the chemical rays. The discovery

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use of alloys in soldering? 863. What is brass? Bell and gong metal? 864. Type metal? Amalgam? 865. What is said of alloys of aluminum? 866. Alloys of gold coin. Of silver? 868. What discoveries were made by Scheele and Ritter?

of photography, or light-drawing, was made by MM. NIEPCE and DAGUERRE of France, who worked jointly upon it for several years. NIEPCE dying in the meantime, it was completed and announced by DAGUERRE in 1839, and in his honor named the *Daguerrotype.*

**869.** The art was, however, at first far from being complete. The process of DAGUERRE applied only to the taking of fixed objects, such as edifices, statues, &c.; the chemicals he employed being so slow in their operation that it required twenty or thirty minutes to take a picture. He endeavored to get an impression of the human face, but it came out a mere blur, and at that time it was believed in Europe that the art was incapable of being applied to portraiture. Dr. J. W. DRAPER of New York, who had long been engaged in researches upon the chemical action of light, by the skilful employment of more sensitive chemicals, first succeeded in taking portraits of the human face, by far the most interesting and important application of the art.

**870. The Daguerreotype** process consists in preparing a highly polished silver surface, usually a plate of copper, silver-coated, and exposing it to vapors of iodine in the dark, when a thin yellow coating of iodide of silver is formed. The plate is then exposed to light in the camera, as has been before stated. A change takes place in proportion to the intensity of the light. But as the effect is a *blackening*, the lightest parts of the objects will become the darkest parts of the picture; so that in the impression the lights and shadows of nature are exactly reversed. When the plate is withdrawn, the image upon it is invisible. It is then exposed to vapor of mercury, which is unequally condensed upon the changed surface; the darkest parts receiving least mercury, the brightest most. The picture is now invisible, but if the plate were exposed to the light, the remainder of the plate would become blackened. It is, therefore, washed with a solution of hyposulphite of soda, which dissolves the remaining iodide. A little solution of the chloride of gold is then poured on the plate, and evaporated over the flame of a lamp. A thin film of metallic gold is thus deposited upon the surface, which improves the appearance of the picture

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Who invented the daguerreotype? 869. What was at first the imperfection of the art? What share had Dr. DRAPER in its improvement? 870. What is the first step of the daguerrean process? How are the lights and shadows reversed? What is the effect of vapor of mercury? Why is hyposulphite of soda used? What is the effect? What is the effect of chloride of gold? What are accelera-

at the same time that it aids to protect it. The first great improvement consisted in introducing more sensitive chemicals, as chlorine, bromine, and their compounds, called *accelerators*, by which the process was quickened.

**871. The Talbotype.**—Mr. Fox Talbot, of England, had been working upon the same subject with no knowledge of what was being done in France. He employed paper instead of a metallic tablet; first brushing it over with a solution of nitrate of silver, and then immersing it in a solution of iodide of potassium. In this way a surface of iodide of silver is obtained, and paper thus prepared may be long preserved. To render it sensitive it is washed over with a mixture of nitrate of silver with gallic and acetic acids, and after exposure in the camera, the picture is brought out by rewashing with the same mixture. The sensitive chemicals are then removed by the hyposulphites, and the picture finished by placing it between sheets of blotting paper, saturated with wax, and pressing a warm smoothing iron over the whole.

**872. Other Methods.**—Mr. Archer, of England, employed glass tablets coated with collodion (943), in which iodide of potassium had been dissolved. It is made sensitive by placing it in a solution of nitrate of silver, the collodion becoming quickly impregnated with iodide of silver. M. Niepce de St. Victor coated the glass with iodized albumen. *Ambrotypes* are taken upon collodion, and finished with a balsam varnish.

**873.** Pictures thus taken, where the lights and shadows of nature are reversed, are called *negatives*. But from these others are taken, and this reverse renders them true to nature, lights answering to lights, and shadows to shadows. These are called *positives*. Pictures are copied by placing the negative against a sensitively prepared surface, and exposing it to light. The parts protected by the dark portions of the negative then become light in the positive, and *vice versa*.

**874. Heliochromy** is the term applied to the art of producing photographic impressions in natural colors. Several colors have been thus reproduced; yellow, which proved the most difficult, has been lately obtained. The colors are not permanent, but recent discoveries have increased their durability.

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tors? 871? How did Talbot prepare his paper? What quality has it? How is the picture finished? 872. What was Mr. Archer's improvement? 873. What are negatives and positives? How are pictures copied? 874. What is heliochromy?

# PART III.

# ORGANIC CHEMISTRY.

## CHAPTER XVIII.

### CHEMICAL NATURE OF ORGANIZED BODIES.

### § I. *Recent Progress of the Subject.*

**875. Organic Chemistry** is that division of the science which considers the chemical composition, properties, and changes of organic substances—or those which have originated in living beings—and such compounds as are derived from them. It forms a highly interesting and very extensive branch of the science, and has been chiefly created within the present century. Organic Chemistry, in its widest significance, embraces all that pertains to the chemistry of life, but it will be desirable here to limit it to the study of *organic substances*,—their compositions, properties, and artificial changes. The chemical relations of living beings will be considered in *Physiological Chemistry*. The present chapter will contain some introductory considerations on the chemical nature and constitution of organized bodies.

**876. Its Claims.**—So new is this department of investigation, that its position has hardly been settled. Some have denied its claim to the rank of a science, and consider its results uncertain and worthless, while others hold that it is the province of chemistry not only to investigate all organic changes, but believe that this branch of the science must go forward until it has completely unravelled the mysteries of organization, and conferred upon the chemist the marvellous power of imitating in his laboratory the productions of living nature. Nor are these sanguine expecta-

875. What is Organic Chemistry? To what is it here limited? 876. What dif-

tions without large warrant, when we consider the vast strides that organic chemistry has recently made. It will be well, however, to define at the outset the present scope and province of this branch of the science.

**877. Its Past Boundaries.**—Organic chemistry has hitherto traced the changes and investigated the products of the natural decay of living bodies. It has also destroyed organic compounds, varying the conditions, and thus giving rise to a host of artificial products. Moreoever, it was able to imitate many of the curious changes of living nature, transforming one organic compound into another of equal grade, as for example, starch into sugar. It has been generally believed that organic chemistry stops here; a fundamental distinction between the two great divisions of the science being, that while in mineral chemistry the operator can both decompose and combine, in organic chemistry he can only destroy but cannot build up. Vital power alone, it is said, can unite the simpler into higher and more complex substances. This has been true in the past state of the science, but it is so no longer.

**878. Artificial Organic Bodies.**—It has been for some time known that the chemist could produce a few of the lower organic substances. One of the earliest and most remarkable instances of organic synthesis was the artificial production of urea by WÖHLER; but it was said of this and similar instances that they were not true, or complete syntheses, as cyanogen and ammonia, the substances used to start with, were organic products which the chemist could not directly form, and which originate only in the domain of life. But this objection has now lost its force. *The chemist, in his laboratory, can create complex organic substances of a high order*, beginning with the ultimate elements, and in his mode of doing this he seems to have surpassed nature herself. Carbonic acid, water, and ammonia are the materials which *she* furnishes as the starting point of organic construction; but the organizing plant cannot begin with the ultimate elements, carbon, oxygen, hydrogen, and nitrogen.

**879. Berthelot's Researches.**—An unexpected and remarkable advancement of organic synthesis has recently been made by

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ferent views are held concerning it? 877. What was the former limit of the science? What is the distinction generally made between organic and inorganic chemistry? Is it a true distinction? 878. What is said of the production of urea? What can the chemist create? 879. State the aim of BERTHELOT'S re-

Berthelot of France. This chemist has devoted himself to the formation of organic substances, synthetically, by combining their elements, through the aid of chemical forces only. In his late work he says: 'We have taken for a point of departure the simple bodies—carbon, oxygen, hydrogen, and nitrogen, and have constructed, by combination of these elements, organic compounds; first, binary, then ternary, &c., the former analogous to, the latter identical with the proximate principles contained in living beings themselves. The substances that we first prepare by methods purely chemical are the principal *carbides of hydrogen*—the fundamental binary compounds of organic chemistry.

880. As a means of producing all the parts from the elements themselves, we take *oxide of carbon*—a substance purely mineral—and by the concurrent influence of time and ordinary affinity (with the aid of pressure and the presence of an alkali), we thus obtain a first organic compound known as *formic acid*. This acid, united to a mineral base, produces a *formate;* then, decomposing this formate by heat, we compel the carbon of the oxide of carbon and the hydrogen of the water to combine in the nascent state, and produce *carbides of hydrogen*.

881. **Artificial Production of Alcohol and Sugar.**—Thus there is formed *marsh gas*, $C_2H_4$; *olefiant gas*, $C_4H_4$, and *propylene*, $C_6H_6$. This is the first step of synthesis. The hydrocarbons thus prepared become the starting point for the synthesis of alcohols. With marsh gas and oxygen we form *methylic alcohol;* with olefiant gas and water, *ordinary alcohol*. The artificial production of the carbides of hydrogen and of the alcohols constitutes the true difficulty; but these once obtained by the ordinary chemical forces, other organic compounds become easy.' Berthelot, conjointly with De Luca, has converted the hydrocarbon propylene into *glycerin*, a proximate principle of the fats; and he has further transformed glycerin into one variety of *sugar*.

882. **Limit to Organic Synthesis.**—This constructive chemistry will, of course, go on until many other compounds are artificially formed; but there is a limit, beyond which it cannot pass. There are two classes of bodies found in the living world which may be distin-

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searches. What was the first step of the process? 880. How did he produce formic acid? What were the next bodies formed? 881. Give the products of the first steps of synthesis. The next products. What was the chief difficulty? What other bodies did Berthelot and De Luca form? 882. What two classes of

guished as *organic* and *organized.* The first, as acetic acid, sugar, and alcohol, resemble inorganic bodies in having a definite composition, and many of them take on a crystalline form. Organized bodies, on the contrary, are less definite in composition, never crystallize, and have rounded outlines; they have an *organized structure*, as seen in the vegetable leaf and animal muscle. We have no reason to suppose that this class of bodies can ever be produced by methods of art.

## § II. *Constitution of Organic Compounds.*

**883.** To draw an exact line between organic and inorganic chemistry is impossible; indeed the latest and most purely scientific treatises, as those of Berthelot and Oddling, entirely ignore the distinction. Yet, there are certain marked peculiarities which contrast organic substances with those which we have been considering. In the first place, they are much less permanent, more mobile and changeable. Plants and animals rapidly grow, and as rapidly decay. While they live they are the theatres of incessant change, and when life ceases, the transformations go swiftly forward till dissolution carries back the materials to the fixed, or inorganic state. This is a fundamental condition of organization, and chemistry has thrown much light on its causes.

**884. The Organic Elements.**—While inorganic chemistry is concerned with the entire array of elementary substances, organic chemistry deals with but few of them. Of the 64 elements, only four, viz., carbon, oxygen, hydrogen and nitrogen, compose the chief mass of the vegetable and animal kingdoms. Besides these elements, organized bodies contain also a small proportion of mineral matter—the ash that is left after they are burned. It consists of ten or twelve elements forming metallic bases, acids, and salts, as are shown by the Chart and Atlas.

**885. Complexity of Organic Substances.**—The list of organic compounds is almost endless, and is rapidly extending. It is an interesting question how, from three or four elements, such a multitude of substances, with so infinite a diversity of properties, can

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bodies are found in the living world? To what is constructive chemistry limited? 883. What is said of the distinction between organic and inorganic chemistry? What fundamental distinction is mentioned? 884. Name the chief organic elements. 885. What interesting question is suggested? What is the com-

arise. Nothing like it is to be found in inorganic chemistry. While mineral substances consist of but few atoms, organic compounds contain a great number. Thus an equivalent of potash has 2 atoms, carbonic acid 3, and ammonia 4, while sugar contains 34 atoms, stearine 236, and albumen nearly 900. We have, therefore, a reason for the instability of organic substances. As complicated machinery is always most easily deranged, so, in chemistry, the more complex a substance, the more readily is the balance of its affinities disturbed by slight causes. The large-atomed organic masses are thus easily decomposed into a host of simpler compounds.

**886. Contrasts of the Elements.**—A further cause of instability is seen in certain remarkable contrasts of properties exhibited by the organic elements. Thus, while carbon is the most invincible of solids, and cannot be liquefied by any amount of heat, the other three are equally invincible gases, and cannot be condensed into liquids by the intensest cold, aided by many thousand pounds' pressure on the square inch. While carbon manifests the strongest atomic cohesion of all the elements, hydrogen is its extreme antithesis, exhibiting the most perfect mobility of atoms. Again, while oxygen manifests the widest and intensest range of attractions of all the elements, nitrogen is the very type of inertness and indifference.

**887. Each Element Influences the Compound.**—We trace in organic compounds the influence of the prevailing elements. Carbon is the universal solidifying constituent. It exists in all organic substances, so that organic chemistry was defined by LAURENT as 'the chemistry of carbon compounds.' But if carbon imparts solidity, the gases with which it is associated give fluency and mobility. Organic compounds thus have a freedom of change which is variable, but intermediate between the unchangeable carbon and the volatile gases. Carbon imparts combustibility, as does also hydrogen in a still greater degree. The class of bodies in which these elements predominate—the hydrocarbons—are the most inflammable, and a portion of the class have a dietetical value based upon this character.

**888.** Nitrogen imparts non-combustibility and changeable-

parison as to number of atoms? Examples. Why are organic bodies unstable? 886. How are the organic elements contrasted? 887. What influences organic compounds? Examples. How did LAURENT define organic chemistry? What

ness;—the nitrogenous group burn with difficulty, and are very prone to decomposition. The act of forming organic substances consists in liberating them from oxygen, so that they may be regarded as high in the organic scale just to the degree in which they are freed from this element. Those having an excess of oxygen, as the vegetable acids, are of the lowest organic grade. We here see a cause of class-diversities among organic substances.

**889. Influence of Composition.**—Of course organic compounds will vary in properties with varying composition. Thus, if we remove from alcohol the elements of an atom of water, it is changed to ether; if it lose a little hydrogen, it is converted into aldehyd; and if it then acquire a little oxygen, it becomes acetic acid—the proportions of carbon remaining all the time unchanged.

Fig. 265.

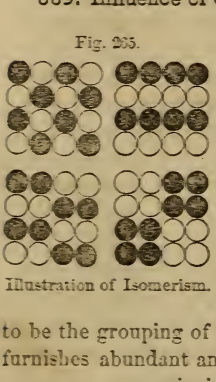
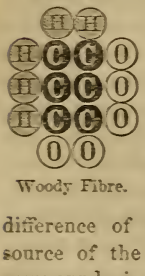


Illustration of Isomerism.

**890. Isomerism and Allotropism.**—Another and inexhaustible source of diversity among organic compounds is believed to be the grouping of their constituent atoms. Organic chemistry furnishes abundant and varied evidence of the operation of this principle, numerous bodies being convertible into each other without loss or addition, by the mere regrouping of their atoms. In Fig. 265 the circles represent atoms, and their successive rearrangements may illustrate the altered grouping of a compound. Figs. 266 and 267 show the isomerism of woody fibre and gum, and how their difference of properties may be caused. Another source of the diversity of properties and plasticity of organic compounds, is very probably the remarkable allotropic variations of their constituents. We have seen how marked this property is in sulphur, oxygen, and phosphorus. Carbon, also, the universal and essential constituent of organic compounds, has its threefold

Fig. 266.



Woody Fibre.

Fig. 267.

Gum.

is said of their freedom of charge? 888. What property does nitrogen impart? What affects the properties of organic substances? Example. 890. How does isomerism explain diversities of organic bodies? Allotropism? 891. What distinc-

aspect. That the elements carry their allotropic conditions into combination seems to have been lately established by BRODIE, who has succeeded in producing several compounds of carbon in which it evidently exists in the state of graphite (528). See Atlas.

## § III. *Colloid Condition of Matter—Dialysis.*

**891.**—The recent distinction of bodies into crystalloid or crystal-like, and colloid or jelly-like, has been stated; but the view is of such importance in connection with organic phenomena as to require further explanation.

**892. Their Contrasted Properties.**—It was said that the crystalloids as water, acids, saline compounds, sugar, &c., tend to assume hard forms with angular outlines; that they are easily soluble, and form solutions which are mobile, or without viscidity. Colloid bodies, on the contrary, as albumen, gum, glue, starch, &c., are soft, with rounded outlines, have little or no tendency to crystallize, are slowly soluble, and form viscid solutions.

**893. Power of Diffusion.**—In this respect there is a further important contrast of properties. This may be shown by providing two jars and placing in one a little colored crystalloid, as bichromate of potash, and in the other a colored colloid, as caramel (burnt sugar). If each be covered several inches deep with another colloid, as starch jelly for example, after a few days it will be observed that the potash salt has diffused upward through the gelatinous mass, while the caramel has hardly discolored the jelly immediately above. This experiment illustrates a most important general principle, viz.: that crystalloids diffuse actively through colloids, and that colloids will not diffuse through each other.

**894. Dialysis.**—These facts open a new source of analysis. If a small hoop be prepared and one side of it be covered with strong paper (942), it forms a vessel like a sieve. Let this be floated upon pure water, and a mixture of crystalloids and colloids, as sugar and gum, be placed upon it. The paper is a colloid, and the crystallized sugar will diffuse rapidly through it into the water below, while hardly a trace of gum will pass. Any animal membrane, or a layer of gum, gelatine, or albumen, when used as a partition, acts

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tion of bodies is important in organic chemistry? 892. Give some of their contrasted properties. 893. What are their powers of diffusion. What does this experiment illustrate? 894. Describe the experiment with the sieve. What is this mode of

in the same manner, transmitting crystalloids and arresting colloids. Prof. GRAHAM calls this mode of separation *dialysis*.

**895. A New Theory of Osmosis.**—These views afford a new explanation of osmose (70). GRAHAM maintains that it is not true capillary attraction which causes the flow of liquids through moist membranes, as formerly described, but that it is due to a combination and decomposition taking place in the membrane. When a colloidal membrane is in contact with pure water upon one side, and a saline solution on the other, it combines with the water, but the saline solution, having a stronger attraction for the water than the membrane has, takes it away, and thus, by a constant hydration and dehydration of the intervening colloid, the motion of the currents is established.

**896. Further Contrasts.**—There are still other contrasts between these two classes of bodies which throw light upon organic changes. The crystalloids are of a permanent nature, while the colloids are unstable. The former, from their hardness, are comparatively unaffected by external agencies, while the latter, from their softness, are extremely susceptible to them. As might be supposed, the living body is formed of soft, impressible colloids, albumen, gelatin, fibrin, &c. As the colloids cannot diffuse into each other, they are adapted for fixity of structure; while, from their ready permeability by water containing crystalloid materials, they give rise to the motion of fluids.

**897. Mutability of Colloids.**—Moreover, while the chemical equivalents of the crystalloids are generally low, those of the colloids are always high. The crystalloids have a decided taste, and are chemically active, while the colloids, from their high equivalents, and the *massiveness* of their complex atoms, are chemically inert, and insipid to the taste. But, physiologically, these relations are exactly reversed. The colloids are the seat and instruments of change; they not only impel the circulations; but, from their complexity and mutability, they are themselves capable of those rapid decompositions and transformations which are necessary for the manifestation of the vital actions. Having contributed for a while to the stability of the structure, they break up into the

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analysis called? 895. What is GRAHAM'S new theory of osmose? How are the osmotic currents established? 896. State other contrasts between crystalloids and colloids. How do these properties affect the living body? 897. How do crystalloids and colloids differ chemically? How physiologically? 899. What does prox-

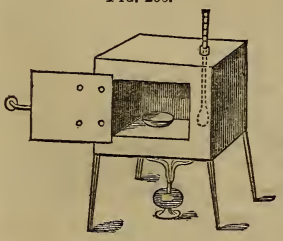
simpler forms of crystalloids, and then rapidly diffuse away as waste products.

898. Speaking physiologically, the crystalloid has been termed the *statical* condition of matter, and the colloid the *dynamical*. GRAHAM remarks that the colloids possess *energia*, and may be looked upon as the primary source of the force appearing in the phenomena of vitality.

## § IV. *Organic Analysis.*

899. **Proximate Analysis** determines the proportions of the proximate principles of organic bodies; for example, the starch, sugar, gluten, ligneous fibre, and oily matter in the flour of wheat. The first step consists in thoroughly drying the substance to be analyzed by exposure to a heat of from 212° to 250° in an oven with double sides, inclosing water, brine, or oil, to maintain a steady temperature, which is indicated by a thermometer, Fig. 268. The proportions of water and solid matter are thus ascertained. The dried product is then exposed to the action of various substances in succession. Water dissolves sugar and gum, ether the fatty bodies, alcohol various crystallizable organic principles, such as vegetable alkalies; while diluted acids and alkalies are employed to effect other solutions; they must always be used cautiously, however, as they tend to decompose organic matter.

FIG. 268.



Drying Oven.

900. **Use of the Microscope.**—In this kind of analysis the microscope is of great use in determining the completeness of separation, as it is often better fitted for the detection of organic particles than any chemical tests that can be applied. For this reason the microscope has been made to do excellent service in the detection of adulterated mixtures of food.

901. **The Mineral Elements** of organized bodies are procured by taking a weighed portion of dry organic matter and carefully

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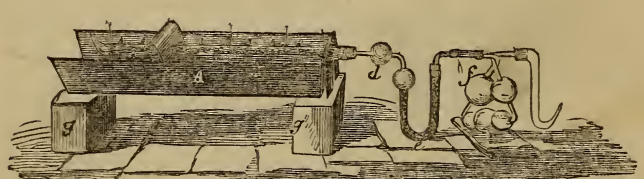
imate analysis determine? What is the first step? What the next process? 900. Is the miscroscope useful? 901. How are the mineral elements procured? 902. In what does ultimate organic analysis consist? 903. Describe the apparatus

burning away the combustible part. The ash that remains is then submitted to the action of various solvents, and its several ingredients ascertained.

**902. Forms in which Elements are obtained.**—As the chief bulk of most organic substances consists of carbon, oxygen, hydrogen, and nitrogen, ultimate organic analysis consists in determining the proportion of these elements. They may be obtained either separately or in a state of combination, but the latter method is most practicable. Nitrogen is generally produced in the form of ammonia; hydrogen as water, and carbon as carbonic acid.

**903. The Apparatus of Analysis.**—The analysis of a body containing carbon, oxygen, and hydrogen is effected in the following manner: A sheet iron furnace in the form of a trough, *A*, Fig. 269, rests upon bricks, *g g*. A tube known as the *combustion tube*,

Fig. 269.




Apparatus for Organic Analysis.

half an inch in diameter and fifteen inches long, rests upon supports in the furnace. This is closed at one end, and filled with dry oxide of copper mixed with the substance to be analyzed. Oxide of copper is used because it readily imparts oxygen to combustibles in contact with it, but when heated alone, it bears a very high temperature without being decomposed. This tube is tightly connected by a cork to the drying tube, which is filled with chloride of calcium, and accurately weighed; *f* represents Liebig's *potash bulbs* which contain solution of caustic potash. These are also carefully weighed and attached to the drying tube by air-tight connection.

**904. The Process.**—The combustion tube is surrounded with charcoal and heated to redness. A portion of the oxygen of the copper, seizing upon the hydrogen of the organic body, forms

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for organic analysis. 904. Describe the process. 905. How is the oxygen de-

water, which, passing off as vapor, is either condensed at *d*, or absorbed by the chloride of calcium. Another portion of the oxygen, combining with the carbon, forms carbonic acid, which, passing through the drying tube, enters the bulbs, and is absorbed by the potash. When the combustion is complete, the potash tube is detached and weighed, the gain being in carbonic acid, three tenths of which is carbon. The chloride of calcium tube is also weighed; its increase is water, one ninth of which is hydrogen. As there is no other source for the carbon and hydrogen than the organic body, the quantity which it contained is thus determined.

**905. Determining the Oxygen.**—But the carbon and hydrogen together do not equal the weight of the original substance; the deficiency is ash and oxygen. The proportion of ash being ascertained by incineration of another sample, the quantity of oxygen is the remaining deficiency, and is easily calculated.

**906. Determining the Nitrogen.**—If the compound to be analyzed contain nitrogen, its quantity must be determined by a separate process. When heated in a suitable apparatus with an excess of hydrate of potash, the whole of the nitrogen escapes in the form of ammonia, which is easily collected, weighed, and the proportion of nitrogen determined.

**907.** Of course this is but the barest outline of the process, and is designed only to convey a general idea of the mode of procedure. Numberless precautions and particulars of the most delicate nature have to be observed, and only a consummate skill of manipulation can produce trustworthy results.

**908. Organic Equivalents.**—The information furnished by bare analysis is but scanty; it does not give the combining proportions of a compound, or the number of its atoms. To obtain these, the unknown substance must be made to unite with some compound, the constitution of which is established. Various well-determined mineral substances are used—very frequently oxide of silver, which combines with many organic bodies. Its equivalent is $Ag108+O8=116$. If it be desired to determine the combining number of acetic acid, a weighed portion of the oxide is made to unite with the acid, of which it takes an equivalent quantity.

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termined? 906. How the nitrogen? 907. What is necessary to obtain trustworthy results? What does bare analysis fail to give? 908. How are organic equivalents

Suppose that the acetate of silver formed amounts to 48.73 grains. It is then burned. The acetic acid and the oxygen of the silver, are both driven off, the loss being 17.24 grs., and there are 31.49 grs. of pure metallic silver left. Then

| Amount of silver. | | At. wt. of silver. | | Amount of acid. | | At. wt. of acid. |
|---|---|---|---|---|---|---|
| 31.49 | : | 108 | : : | 17.24 | : | 59 |

This product, 59, is, however, too high, as it includes the oxygen of the silver, which escapes with the acid. Deduct this, and we have 51 as the true atomic weight of acetic acid.

**909. Calculating Formulæ.**—If now, by the process (904), we analyze the same quantity of acetic acid, we shall find that it contains 24 parts carbon, 3 hydrogen, and 24 oxygen. These quantities divided by the atomic numbers of the elements, give 4 equivalents of carbon, 3 of hydrogen, and 3 of oxygen, or $C_4H_3O_3$, as the empirical formula of acetic acid.

## § V. *Theory of Compound Radicles.**

**910. Importance of Grouping.**—The recent advance in chemistry compels us to the conclusion that the *arrangement* of atoms is of more significance than either their proportions or their kinds. Formerly organic compounds were classified according to their obvious properties, as acids, bases, &c.; but at the present time the strict scientific method is to distribute them into groups and series according to relationships of derivation and analogies of atomic arrangement. The doctrine is worked out in different ways by different authorities, and though chiefly of importance to the advanced chemist, it will be also interesting to the general student, as developing many curious facts and illustrating the direction of progressive thought.

**911. Compound Radicles** have been referred to as combinations of elements, which play the part of simple bodies, so that we

* "The German term *radikal* is commonly but inaccurately translated *radical*, which is properly an adjective, the word *radicle* being the appropriate rendering." (MILLER.)

obtained? How is the combining number of acetic acid obtained? 909. How is the formula determined? 910. What is said of the arrangement of atoms? How were organic compounds formerly classified? What is the present strictly scientific method? 911. What are compound radicles? Give the combinations of the simple

may trace them in their relations and changes as we do the elements themselves. Potassium, for example, is an element; it combines with oxygen, forming oxide of potassium KO, and this again combines with water, forming KO, HO, or hydrated oxide of potassium. If, in place of water, nitric acid be used, we have nitrate of oxide of potassium, $KO, NO_5$, or with other acids, a large class of salts of oxide of potassium. Potassium is here regarded as the starting point, the root, or *radicle*, of this series, and, being undecomposable, it is called a *simple radicle*.

**912. Example.**—Now there are compounds or groups of elements which behave in a similar way, and are hence called *compound radicles*. Ethyl, for example, is a radicle with the composition $C_4H_5$, and gives rise to a series of compounds, like potassium: thus,

| | |
|---|---|
| Ethyl, | $C_4H_5$ |
| Oxide of ethyl (wine ether), | $C_4H_5, O$ |
| Hydrated oxide of ethyl (common alcohol), | $C_4H_5, O, HO$. |

As potassium combines with sulphur, chlorine, iodine, &c., to form a series of salts, so ethyl combines with the same elements to form a series of ethers, as follows:

| | | | |
|---|---|---|---|
| Oxide of potassium, | KO | Oxide of ethyl, | $C_4H_5O$ |
| Sulphide of potassium, | KS | Sulphide of ethyl, | $C_4H_5S$ |
| Chloride of potassium, | KCl | Chloride of ethyl | $C_4H_5Cl$ |
| Iodide of potassium, | KI | Iodide of ethyl, | $C_4H_5I$ |
| Bromide of potassium, | KBr | Bromide of ethyl, | $C_4H_5Br$ |

In the last column we have a series of ethers, in which S, Cl, I and Br replace the O of common ether. Other compound radicles, as methyl ($C_2H_3$) and amyl ($C_{10}H_{11}$), give rise in the same way to different series of ethers and alcohols.

**913.** It was at first objected to this theory that the radicles were hypothetical bodies, which could not be separated or proved to exist. To this it is replied, that several of them *have been separated*, while the view they afford greatly assists the comprehension of organic changes. See Chemical Atlas and Chart.

## § VI. *Homologous Series.*

**914.** Homology is a term used to express an interesting relation among organic substances, which has been made by GERHARDT

radicle potassium. 912. In what way do compound radicles act? Example. 913. What objection was made to this theory? How answered? 914. What is GER-

the basis of classification in his system of chemistry. A series of compounds is called *homologous* when each member of it—that is, each compound—differs from the others in a regular manner, either by a uniform number, as $C_2H_2$, or its multiple; and when the properties of these different compounds are entirely analogous, yet differ in degree in proportion to the varying composition.

**915.** There is a class of compounds, for example, known as alcohols, which manifest a close analogy with each other, both in composition and in their modes of decomposition. In the subjoined table the composition and homology of the most important of this group of bodies is represented.

| Homologous Series of Alcohols. | | Homologous Series of Volatile Acids. | |
|---|---|---|---|
| Methylic alcohol, | $C_2H_4O_2$ | Formic acid, | $C_2H_2O_4$ |
| Common alcohol, | $C_4H_6O_2$ | Acetic acid, | $C_4H_4O_4$ |
| Propylic alcohol, | $C_6H_8O_2$ | Propylic acid, | $C_6H_6O_4$ |
| Butylic alcohol, | $C_8H_{10}O_2$ | Butyric acid, | $C_8H_8O_4$ |
| Amylic alcohol, | $C_{10}H_{12}O_2$ | Valerianic acid, | $C_{10}H_{10}O_4$ |
| Caproic alcohol, | $C_{12}H_{14}O_2$ | Caproic acid, | $C_{12}H_{12}O_4$ |
| Caprylic alcohol, | $C_{16}H_{18}O_2$ | Caprylic acid, | $C_{16}H_{16}O_4$ |
| Laurylic alcohol, | $C_{24}H_{26}O_2$ | Lauric acid, | $C_{24}H_{24}O_4$ |
| Cetylic alcohol, | $C_{32}H_{34}O_2$ | Ethalic acid, | $C_{32}H_{32}O_4$ |
| Cerylic alcohol, | $C_{54}H_{56}O_2$ | Cerotic acid, | $C_{54}H_{54}O_4$ |
| Melissylic alcohol, | $C_{60}H_{62}O_2$ | Melissic acid, | $C_{60}H_{60}O_4$ |

Here it will be seen that the first six of the alcohols differ by the successive addition of $C_2O_2$, and the rest by its multiples. Formulæ have been constructed to represent these compounds in which *n n* stands for 2, 4, 6, 40, or any even number of atoms of carbon and hydrogen, and by which the composition of the alcohols is indicated, thus $C_nH_{n+2}O_2$.

**916.** When any compound of a homologous series is decomposed, it gives rise to compounds which are definitely related to it, but as they are differently constituted, they are termed *heterologous* compounds. The alcohols, when decomposed, give rise to a series of ethers, of aldehyds, and of acids;—heterologous groups, but each forming a homologous series. The most complete of this series is that of the volatile acids, some of which are given in

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HARDT'S basis of classification? What is a homologous series of compounds? 915. Example. How do these compounds differ? How are they represented in formulæ? 916. What are heterologous compounds? Example. What is the most complete of this series, and from what derived? What is their difference and for-

the table. They are derived from the alcohols by oxidation, and several of them occur in nature. They differ by an increment of $C_2 H_2$, and have the following general formula, $C_nH_nO_4$

**917.** The extreme terms of this series are widely separated in properties; formic acid being a pungent, corrosive, volatile liquid, which must be cooled to 32° to solidify it, while melissic acid is a solid fat which melts at 192°. But if we compare any compound of the series with the adjoining ones, the difference in properties will be found but slight. They increase in solidity, and their melting and boiling points rise gradually with each successive increase of the common difference. But a part of the series is given in the table; it rises uninterruptedly, step by step, from 2 to 38 equivalents of carbon and hydrogen, through nineteen links of the homologous chain; above this there are gaps not yet filled. A few years ago only the first two members of the series were known. For illustrations of this and the following subject, see the Chemical Atlas.

## § VII. *Theory of Types.*

**918.** Convinced of the difficulty of representing the actual arrangement of the atoms of chemical compounds, many chemists maintain that we should represent in formulæ only those relations and analogies among compounds which result from their *modes of decomposition*, when subjected to the action of the same chemical reagents. To effect this, all substances are thrown into a few great classes of analogues, and some leading member of each division, having familiar and well-marked characteristics, is selected as the pattern or *type* of the class, from the formula of which that of all the others is derived. This view puts resemblance of chemical properties out of the question; hence the same type may comprehend acids, bases, and neutral bodies.

**919.** GERHARDT refers most of the bodies of organic chemistry to four principal types, as follows—the first column representing the types, and the second giving single examples of compounds arranged under them:

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mula? 917. What is said of the extreme terms of this series? How do the compounds differ successively? What is further said of this series? 918. What do many chemists maintain in regard to formula? How is this result obtained? What is further said of this view? 919 What are GERHARDT's four principal

| | | | |
|---|---|---|---|
| 1. The hydrogen type, | $\left.\begin{matrix}H\\H\end{matrix}\right\}$ or $H_2$ | Marsh gas, hydride of Methyl, | $\left.\begin{matrix}C_2H_3\\H\end{matrix}\right\}$ |
| 2. The chloride or Chlorohydric acid type, | $\left.\begin{matrix}H\\Cl\end{matrix}\right\}$ | Chlorohydric ether, | $\left.\begin{matrix}C_4H_5\\Cl\end{matrix}\right\}$ |
| 3. The oxide or Water type, | $\left.\begin{matrix}H\\H\end{matrix}\right\}O_2$ | Alcohol, | $\left.\begin{matrix}C_4H_5\\H\end{matrix}\right\}O_2$ |
| 4. The nitride or Ammonia type, | $\left.\begin{matrix}H\\H\\H\end{matrix}\right\}N$ | Ethylamine, | $\left.\begin{matrix}C_4H_5\\H\\H\end{matrix}\right\}N$ |

**920. Substitution and Replacement.**—When the idea of a type is accepted, the changes that take place under it are regarded as replacements or substitutions. It is like preserving the general structure of an edifice, though constantly removing its individual bricks and stones and replacing them by others. Thus in the chloride type we can substitute for the chlorine, iodine, bromine, or cyanogen, while the type remains unaltered.

**921.** Perhaps the most interesting case of substitution is where ammonia is converted into a complex organic base by replacing its hydrogen with various compound radicles. If bromide of ethyl be made to act upon ammonia, a new base ethylamine, $C_4H_7N$, appears. This is a compound of the ammonia type, $\left.\begin{matrix}H\\H\\H\end{matrix}\right\}N$, and may be represented thus, $\left.\begin{matrix}C_4H_5\\H\\H\end{matrix}\right\}N$; that is, it is ammonia in which one atom of hydrogen has been displaced by its equivalent of ethyl, $C_4H_5$. If this new compound be heated with bromide of ethyl, diethylamine is obtained, $\left.\begin{matrix}C_4H_5\\C_4H_5\\H\end{matrix}\right\}N$; that is, another atom of hydrogen is replaced by an atom of ethyl. Again, the last atom of hydrogen may be replaced by the radicle, and triethylamine results, $\left.\begin{matrix}C_4H_5\\C_4H_5\\C_4H_5\end{matrix}\right\}N$. Thus a new ammonia is formed, closely resembling in properties common ammonia.

**922.** Another remarkable instance of this substitution is that of chlorohydric ether, $C_4H_5Cl$. Chlorine combines with this ether, forming a series of five new compounds, in which it displaces the hy-

types? 920. How are changes that take place under a type regarded? What comparison is made? Example. 921. What remarkable case of substitution is given? What is the composition of ethylamine? Diethylamine? Triethylamine? 922.

drogen, equivalent for equivalent, until the latter element is all removed, and the compound completely chlorinated. Neither the number of atoms in the compound, nor their arrangement are changed in this complete revolution of composition, while the boiling point and density steadily rise as the quantity of chlorine increases.

**923. Coupling of Organic Compounds.**—We have just seen that there is a class of substances produced by the union of two or more simple organic compounds, yet retaining the character of one and losing that of the other. Thus, ethyl unites with ammonia, its own characteristic properties disappearing, while those of ammonia continue. The terms *coupling*, or *conjugation* of compounds, have been applied to this kind of union, while that constituent whose properties disappear is called the *copula.*

**924.** The foregoing views are not sufficiently developed to serve as a basis of popular classification. We shall adopt an arrangement less strictly scientific, but more convenient for the general student.

The chief vegetable and animal products, and their most important changes, will be noticed in the following order :—

1. *The saccharine and amylaceous group.*
2. *The oleaginous group—fats and oils.*
3. *Acids, bases, and coloring principles.*
4. *Nitrogenous compounds, their changes and products.*
5. *Animal products.*
6. *Chemistry of foods.*
7. *Chemistry of soils.*

## CHAPTER XIX.

### THE SACCHARINE AND AMYLACEOUS GROUP.

**925.** This is an important class of organic bodies, composing the chief bulk of the vegetable kingdom, and entering largely into the diet of animals. They are distinguished by several chem-

Give another case of this substitution. How is the compound affected by this revolution ? 923. What is coupling of compounds ? 924. What is said of these views ? 925. What is the relation of the saccharine and amylaceous group to the

ical peculiarities. Containing no nitrogen, they are termed the *non-nitrogenous* group; being composed of three elements, carbon, hydrogen and oxygen, they are known as the *ternary* group; and, as they contain hydrogen and oxygen in the exact proportion to form water, they have been called *hydrates of carbon*. We cannot say, however, that the hydrogen and oxygen exist in these compounds as water. Their mode of origin and mutual relations in the plant will be noticed in the chapter on vegetable growth.

## § I. *The Sugars.*

**926.** These sweet-tasted bodies are widely distributed through the vegetable kingdom, and largely employed as food. There are several varieties of sugar, but we can notice only three: cane sugar, or *sucrose;* grape sugar, or *glucose;* and milk sugar, or *lactose.*

**927. Cane Sugar,** $C_{12}H_{11}O_{11}$ (*Sucrose.*)—This, the most important variety, has a specific gravity of 1.6, is soluble in one third its weight of cold water, forming a thick sirup, and is the sweetest of all the sugars. When evaporated from its solutions it readily crystallizes; but when long boiled it acquires an atom of water, loses its property of crystallization, and acquires an acid reaction. If boiled for some hours, with a trace of acid added, it is changed to grape sugar, $C_{12}H_{12}O_{12} + 2\,Aq$. In its chemical relations sugar ranks with acids; it dissolves and combines with various bases, forming *saccharates;* as $2\,PbO, C_{12}H_{10}O_{10}$, saccharate of lead. Sucrose melts at about 320°, and by cooling forms the transparent, amber-colored solid known as *barley sugar.* If the melted sugar be heated to 420°, a brown, bitter mass results, known as *caromel*, which is much used by cooks and confectioners as a coloring agent.

**928. Manufacture of Sugar.**—Cane sugar is chiefly produced from the cane, beet root, sorghum, and the palm and maple trees; but by far the largest portion is from the sugar cane. The canes are crushed by passing them between grooved iron cylinders. The juice, when first expressed, is liable to rapid decomposition

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vegetable and animal kingdoms? How are they named, and why? 926. What are the sugars? Their varieties? 927. Give the composition of cane sugar. Properties. How is it changed to glucose? What are saccharates? Caromel? 928. From what is cane sugar produced? Give the mode of its manufacture.

587



from the heat of the climate. This is prevented by the addition of a small quantity of lime, which neutralizes acids and coagulates impurities. The juice is evaporated by boiling in large open vessels, and when reduced to a proper consistency, is transferred to coolers, where a portion of it crystallizes, forming raw, or brown sugar. On an average, a gallon of juice produces a pound of sugar.

**929. Molasses.**—The drainage of the raw sugar forms molasses. It contains a portion of the sugar that has been burnt and darkened in boiling, another part that has been changed to the uncrystallizable state, and still another of crystallized sugar. It has a strong, peculiar taste, and is acidulous. It is very absorbent of water; indeed many kinds of raw sugar, from this cause, melt into sirup when exposed to the air.

**930. Refining of Sugar.**—Crude sugars are purified, or refined, by reducing them to a sirup and first filtering it through twilled cotton, to separate mechanical impurities. The same effect is further promoted by the use of serum of blood. To decolorize the sirup it is again filtered through a bed of coarsely-powdered charcoal. It is then evaporated in vacuum pans—the air being exhausted, so that it will boil at a lower temperature—and finally recrystallized.

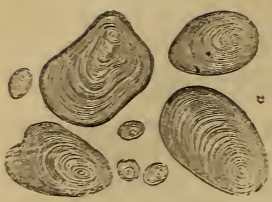
**931. Grape Sugar,** $C_{12}H_{12}O_{12}+2Aq.$ (*Glucose*).—This variety of sugar is less soluble and less easily crystallized than sucrose. We are familiar with it as the sweet grains of raisins, figs and other dried fruits, and it is also largely obtained by transformation of starch (951); hence it is called *starch sugar*. BERNARD has shown that it is normally produced in the livers of animals, and it appears as a morbid constituent of the urine in the disease called *diabetes*. The candied sugar of honey and sweetmeats consists of glucose. Fruit sugar was formerly supposed to be a distinct variety, but it proves to be rather a mixture of different kinds.

**932. Milk Sugar,** $C_4H_{24}O_{24}$ (*Lactose*), is obtained only from the milk of the mammalia, to which it gives its sweetish taste. It is obtained by evaporating clarified whey till it crystallizes. It is much less soluble, and, therefore, much less sweet than cane or grape sugar, and its crystals are hard and gritty.

929. How is molasses obtained? What are its properties? 930. How is sugar refined? 931. How does grape sugar differ from sucrose? From what is it obtained? What is fruit sugar? 932. What is milk sugar, and how obtained?

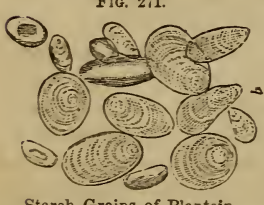
## § II. *Starch.*

FIG. 270.



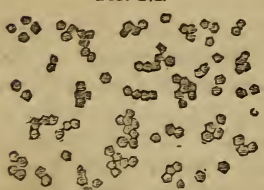
Starch Grains of Potatoes.

FIG. 271.



Starch Grains of Plantain.

FIG. 272.



Starch Grains of Rice.

**933. Starch,** $C_{12}H_{10}O_{10}$ (*Fecula*, *Amadin*).—This substance is found universally distributed in the vegetable kingdom in grains, seeds, roots, and the pith and bark of plants. When pure it is a snow-white glistening powder. Examined by the microscope, it is found to consist of exceedingly minute round, or oval grains, which vary in size from $\frac{1}{100}$ to $\frac{1}{1000}$ of an inch in diameter. Potato granules are much larger than those of wheat or rice. Starch grains from different sources vary also in form and structure. Those of the potato are egg-shaped; those of wheat are lens-shaped; those of rice angular, while several kinds have a grooved aspect, and consist of concentric layers, like the coats of an onion. As each variety has some peculiarity by which it may be identified, the adulteration of wheat flour by potato, or other starches, may thus be detected.

**934. Properties.**—Starch is insoluble in cold water, alcohol and ether, but swells up, and is converted into a paste in water containing 2 per cent. of alkali. If heated in water to 140°, the grains swell and burst, producing a jelly-like mass (gelatinous starch, or *amadin*), which is used to impart a gloss to textile fabrics. The test of starch is iodine, which combines with it, forming a blue compound.

**935. Sources and Varieties.**—Starch is largely procured from potatoes, wheat, and rice. *Corn starch* is obtained from Indian

Properties 933. Give the composition of starch. Where is it found? Its appearance? State the differences in starch grains. 934. What are the properties of starch? Its test? 935. Give the sources and varieties of starch.

corn by chemical agency, being freed from the glutinous, oily, and ligneous elements of the seed, by the aid of alkaline solutions, and by grinding and bolting the corn in a wet condition. *Sago* is a brownish-white starch, obtained from the pith of the palm tree. *Tapioca* and *arrow root* are starches from the roots of West India and South American plants.

**936. Transformations of Starch.**—When commercial starch is heated under pressure to 320°, it becomes soluble in cold water, and is changed into *gum*. It is sold under the name of *British gum*, and is successfully substituted for gum arabic by calico printers in thickening their colors. If gelatinous starch is boiled for a few minutes with weak sulphuric acid, it changes from a viscid mass to a limpid fluid, and a substance is produced called *dextrine*, which resembles gum in properties. It is a transparent, brittle solid, isomeric with starch, soluble in water, incapable of fermentation, and produces *right-handed* rotation in a ray of polarized light; hence its name. If the acid solution of dextrine is boiled for some hours, and the acid removed by neutralizing it with chalk and filtering, the liquid will be found to yield upon evaporation a mass of solid glucose exceeding in weight the starch from which it was produced. The starch has become grape sugar, $C_{12}H_{14}O_{14}$, its increase in weight being due to the acquisition of the elements of water. The sulphuric acid suffers neither change nor loss, but seems to effect the transformation by its bare presence. Unripe fruits contain starch, which by ripening is converted into sugar.

**937. Gum**, $C_{12}H_{11}O_{11}$ (*Arabin*).—These terms are applied to a class of substances which are often seen exuding in globular masses from the bark of trees, as the plum and cherry. Gum is translucent, tasteless, inodorous, and either dissolves in water, or swells up and forms with it a thick mucilage. It exists in small proportion in the cereal grains, but its chief source is tropical trees, from the bark of which it flows in such quantity as to be gathered for commercial purposes. *Gum Arabic*, the product of a species of acacia, is a hard, brittle substance, and is, perhaps, the best known of the gums. Its solution being very adhesive, is used as

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936. What is British gum, and how used? How is dextrine produced? Give its properties. How is it changed to grape sugar? What of unripe fruits?
937. What is gum or arabin? Its sources and properties. What is gum arabic?

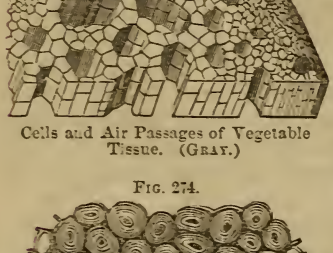
a substitute for paste or glue. *Mucilage* or *bassorin* ($C_{12}H_{10}O_{10}$) is a kind of gum insoluble in water, but which swells into a gelatinous mass when moistened. It abounds in gum tragacanth, and also in quince seeds and linseed.

938. Vegetable Jelly, *Pectin, or Pectic Acid*, is a substance resembling starch and gum in its composition, which gives to the juices of fruits and roots the property of gelatinizing. When boiled a long time it loses its gelatinous property, and becomes of a gummy nature. It is but slightly nutritive.

## § III. *Woody Fibre.*

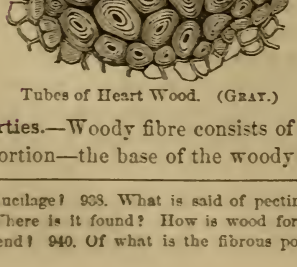
939. Cellulin, $C_{12}H_{10}O_{10}$.—This is the most abundant product of vegetation. Besides forming the chief bulk of all trees, it exists in the straw and stalks of grain, in the membrane which envelops the kernel (bran), in the husk and skin of seeds, and in the rinds, cores, and stones of fruit. Wood consists of slender fibres, or tubes closely packed together. Fig. 273. When first formed these tubes are hollow and serve to convey the sap, but in the heart wood of trees they become filled up and consolidated as shown in Fig. 274, the circulation of fluids taking place in the white external sap wood (*alburnum*). Upon the density with which the fibres are imbedded together depends the property of hardness or softness of wood.

Fig. 273.



Cells and Air Passages of Vegetable Tissue. (Gray.)

Fig. 274.



Tubes of Heart Wood. (Gray.)

940. Composition and Properties.—Woody fibre consists of two parts. Cellulin is the fibrous portion—the base of the woody tissue. It has been known as *cel-*

Mucilage? 938. What is said of pectin? 939. Give the composition of cellulin. Where is it found? How is wood formed? Upon what does its hardness depend? 940. Of what is the fibrous portion of wood composed? State the prop-

*lulose*, but it is better, as MILLER suggests, to change it to cellulin, reserving the termination *ose* for the sugars. Cellulin, when pure, is white, tasteless, and insoluble in water, alcohol, or ether, but dissolves in a solution of oxide of copper in ammonia. It is nearly pure in cotton, linen, and elder pith. In the tissue of cellulin there is deposited a ligneous incrustation called *lignin*, which is the thickening and hardening constituent of wood, and forms the principal part of its weight. It is difficult to separate and has not been obtained pure, nor has its composition been determined. It is deposited mixed with the coloring matter of the wood and with resinous substances, which increase its combustibility.

**941. Transformations of Cellulin.**—Cellulin is not colored blue by iodine, but when digested for a short time in sulphuric acid, it is changed and answers to the test of starch. It may be converted into sugar by the following process. Two parts of linen and cotton threads are soaked for 24 hours in three parts of sulphuric acid, and the mixture is then largely diluted with water and boiled for a few hours. If the acid be then neutralized with chalk, a mass of glucose is obtained which, if the process is well conducted, may exceed in weight the woody fibre employed.

**942. Paper** is made chiefly from waste cotton and linen rags. They are bleached, boiled in alkali, and reduced to pulp by means of a beating engine. The pulp, formed into sheets and dried, is blotting paper. To convert it into writing paper, it is soaked in a preparation of glue and alum (sized), and then pressed between hot iron plates. To make vegetable parchment, thin, unsized paper is plunged for a few moments into a mixture of sulphuric acid and water, and then washed. In some unknown way the fibre is affected and the paper made five times stronger than before the process.

**943. Gun Cotton,** $C_{36}H_{21}9NO_{41}O_{30}$, *Pyroxyline.*—If cotton, linen, sawdust, or paper is dipped into a mixture of equal measures of sulphuric and nitric acid, of sp. gr. 1.520, a remarkable chemical change takes place: 9 atoms of the hydrogen of the cellulin are replaced by 9 equivalents of peroxide of nitrogen ($NO_4$), while the fibre, without being changed in appearance, increases in weight 82 per cent. When removed from the solution and prop-

erties of cellulin. What of lignin? 941. Describe the changes of cellulin. 942. How is paper made? Blotting and writing papers? How is vegetable parchment prepared? 943. What is the composition of gun cotton? How is it prepared?

erly washed and dried, it forms *gun cotton*, discovered a few years ago by Prof. Schönbein. It ignites at 400° (200° below gunpowder), and disappears in an instantaneous flash, leaving hardly a trace of residue. Authorities vary in estimating its explosive force, but the latest make it about three times that of gunpowder. The extreme suddenness of the propulsive force overstrains the gun and produces less effect upon the ball than gunpowder. *Collodion* is formed by dissolving gun cotton in ether containing a small proportion of alcohol. On evaporating the ether, a transparent, adhesive film is left, which is insoluble in water and is used in surgery for protecting wounds from the air. The chief use of collodion, however, is in photography.

## § IV. *Destructive Distillation of Wood.*

**944.** When wood is heated in close vessels, or with but partial access of air, it gives rise to a large number of compounds, depending upon the nature of the wood and the temperature employed. The products of distillation at the lowest temperature, as water and acetic and carbonic acids, contain much oxygen. As the temperature rises the products contain less oxygen, as *creosote*, and *wood spirit*. At a higher heat various hydrocarbons appear, as *eupion*, *paraffin*, while at a red heat pure hydrogen predominates. A residue of charcoal always remains in the retort; in dried hard wood amounting to 25 per cent. of its weight, or $\frac{3}{5}$ of the carbon which the wood contained.

**945. Charcoal and Tar.**—Charcoal is commonly prepared by covering piles of wood with earth, so as partially to exclude the air. The mound or pit is then fired, and the volatile constituents of the wood gradually distilled off, by a slow, smothered combustion, leaving the charcoal. To produce tar, resinous pine woods are used, and the bottom of the pit made concave. As the combustion proceeds, the liquid products are separated, collect at the bottom, and flow out through a trough into a reservoir. They consist of *tar*, *acetic acid*, and *oil of turpentine*. When tar is distilled, essence of turpentine is separated and *pitch* remains.

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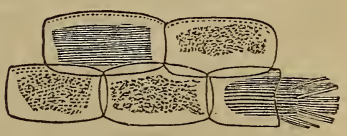
By whom was it discovered? How does it compare with gunpowder? How is collodion prepared? What are its uses? 944. What occurs when wood is heated in close vessels? Mention the successive products. What is the residue? 945. How is charcoal prepared? How is tar produced? What of the liquid products? 946. How is pyroligneous acid obtained? State its properties and

these are *quercitron*, from the bark of the black oak; *fustic*, from the wood of the West Indian mulberry, and *weld*, from the *reseda luteola*. *Annotto*, used in dyeing nankeen, and also to color butter and cheese, is extracted from certain seeds grown in South America. *Turmeric* is obtained from the roots of an East Indian plant.

**1036. Chlorophyll** (*Leaf-green*) is the substance to which the vegetable world owes its uniform green color. It is of a resinous nature, soluble in alcohol and acids, but insoluble in water. Fig. 279 shows the grains of chlorophyll and needle-like crystals in the cells of a leaf. It exists only in minute quantity in plants, the leaves of a large tree, according to Berzelius, containing perhaps not more than 100 grains.

Fig. 279.



Chlorophyll in Cells.

This substance appears to be a direct product of the action of the sunbeam upon vegetation, as it is never seen except in those parts exposed to the light. Plants removed from a dark cellar into the sunlight turn rapidly of a green color, and every one may have remarked in spring how quickly, after a few days of cloudy weather, the unfolding vegetation is changed to a deep green by the rays of the sun. The change from green to red and yellow in the autumn leaves, is supposed to be owing to the oxidation of their chlorophyll.

**1037. Extractive Matter.**—This term has been applied to numerous substances, chiefly vegetable, extracted by chemists, which have not yet been accurately examined. The number of known plants exceeds a hundred thousand, and each possesses peculiar principles in small quantity to which its flavor and medicinal properties are due. Of this vast number, but few comparatively have been studied by chemists, who designate whatever of this kind that is unknown as *extractive matter*.

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is chlorophyll? Why is it thought to be a direct product of the sunbeam? What of the change in autumn leaves? 1037. What does the term extractive matter

# CHAPTER XXII.

## NITROGENOUS COMPOUNDS—THEIR CHANGES AND EFFECTS.

### § I. *The Albuminous Compounds.*

**1038.** The substances now to be noticed differ in very important respects from those hitherto considered. They have more elements; they contain nitrogen in higher proportions, have a larger number of atoms, and are therefore more complex and prone to change. They do not crystallize, and are highly organized. Though originating in the vegetable kingdom, they furnish the basis of the structures of all animal systems. The group comprises albumen, fibrin, casein, and their several modifications, and is hence called the *albuminous* or *albuminoid* group.

**1039. Albumen.**—We are most familiar with this body in the form of white of eggs, a glairy, insipid fluid, which coagulates by heat, producing a white solid; hence its name, from *albus*, white. Albumen forms about 7 per cent. of the blood, and is found in variable proportions in all the secretions of the body. It also exists dissolved in the juices of plants, or dried in their seeds. When the water which has been used to wash starch from wheat flour or scraped potatoes, is allowed to stand until it becomes clear, and is then boiled, it assumes a turbid appearance, and deposits a flaky-white substance, which has the same character as white of egg, and is known as *vegetable albumen.* When dried it forms a brittle, yellow, gummy mass, which dissolves in cold water; but when *coagulated* it will not dissolve in water, either cold or hot. The change of coagulation does not alter its composition. The temperature at which it takes place varies; a strong solution of albumen in water becomes completely insoluble at 145°, and separates in flakes at 167°. The more it is diluted with water, the higher the temperature of coagulation.

**1040. Chemical Properties.**—Albumen consists of carbon, oxygen, hydrogen, and nitrogen—some 16 per cent. of the latter—and a small but definite proportion of sulphur and phosphorus.

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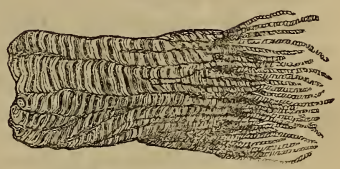
signify? 1038. How do the nitrogenous compounds differ from those hitherto considered? What does the albuminous group comprise? 1039. What is the most familiar form of albumen? Where is it found? What is vegetable albumen? Its properties? 1040. Give the composition of albumen. For what is it an

Its exact composition, however, is not determined. It is coagulated by many substances, as alcohol, strong acids, creosote, and corrosive sublimate; therefore, in poisoning by these bodies, if the white of eggs be promptly swallowed, it seizes upon the noxious compounds and protects the stomach. Albumen, like water, seems capable of combining with both acids and bases. Alkalies render it soluble. White of egg and blood are both slightly alkaline, from the presence of soda; the albumen being supposed to exist as *albuminate of soda*. It forms also definite compounds with the acids. *Vitellin* is the albumen of the yolk of eggs.

**1041. Fibrin** is the name given to the substance which forms the basis or *fibre* of muscular tissue. It occurs in bundles, as shown in Fig. 280, the parallel fibres having wrinkles or cross markings. If a piece of lean beef be long washed in clean water, its red color, which is due to blood, gradually disappears, and a mass of white, fibrous tissue remains which is known as *animal fibrin*. Like albumen, it is capable of existing in two states: the soluble and the insoluble. In its soluble form it is a constituent of blood, forming in the healthy state about 2 parts in 1000 parts of that liquid. The clotting of blood, when freshly drawn, is due to the coagulation of its fibrin, which solidifies into a network of fibres. Dilute solutions of potash and soda dissolve fibrin, as they do albumen.

FIG. 280.



Fibres of lean Meat, magnified.

**1042. Gluten**—*Vegetable Fibrin.*—When wheat flour is made into a dough and then kneaded on a sieve or piece of muslin under a stream of water, its starch is washed away and there remains a gray, tough, elastic substance, almost resembling animal skin in appearance. When dried it has a glue-like aspect, and is therefore called *gluten*. The crude gluten thus prepared, when freed from oil, albumen, &c., proves to be identical in composition with animal fibrin, and is hence named *vegetable fibrin*. Like muscle fibrin, it is soluble in very dilute chlorohydric acid.

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antidote? Its chemical properties? 1041. Describe animal fibrin. What is its relation to blood? 1042. How may gluten be procured? Why is it called vegetable

**1043. Casein** is an essential constituent of milk, existing in it to the extent of about 3 per cent., and forming its curd, or cheesy principle. Its soluble form in milk is due to a small portion of free alkali, and when this is neutralized by an acid, the casein is precipitated, or the milk *curdles*. By neutralizing the acid, the casein is re-dissolved. The water in which flour has been washed contains a small portion of a substance, which is coagulated by acids; it resembles the curd of milk, and is called *vegetable casein*. It is found in large proportion in peas and beans. The Chinese make a cheese from peas which gradually acquires the smell and taste of milk cheese.

**1044. Chemical Composition.**—There is a remarkable identity in composition among the members of this group. The analysis of albumen from the hen's egg gives carbon 53.5, hydrogen 7, nitrogen 15.5, oxygen 22, sulphur 1.6, phosphorus 0.4; and, with slight variations in the proportions of sulphur and phosphorus, this may represent the composition of the whole group. LIEBIG gives the following formula as the best approximation yet obtained toward their composition:

| | |
|---|---|
| Albumen of blood, Albumen of flesh, Fibrin of flesh, | $C_{216}\ H_{169}\ O_{68}\ N_{27}\ S_2$ |
| Albumen of eggs, | $C_{216}\ H_{169}\ O_{69}\ N_{27}\ S_3$ |
| Casein, | $C_{288}\ H_{223}\ O_{90}\ N_{36}\ S_2$ |
| Fibrin of blood, | $C_{298}\ H_{228}\ O_{92}\ N_{40}\ S_2$ |

An important fact concerning these compounds is that they are physiologically isomeric—are convertible into each other in the animal system.

**1045. Protein.**—When these albuminoids are dissolved in a solution of potash or soda by a gentle heat, if an acid be added, a grayish precipitate is formed, which is attended with the liberation of sulphur and phosphorus in the form of sulphuretted hydrogen and phosphoric acid. MULDER calls this substance *protein*, and he and many other chemists regard it as the radicle or base of the whole group. They hold it to contain neither sulphur nor phosphorus, and suppose the different albuminous bodies to be formed by combinations of protein with these elements and oxygen. LIEBIG and his adherents deny that any such radicle has ever been freed from sulphur, and reject the doctrine of protein altogether.

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fibrin? 1043. Describe casein. What occasions the curdling of milk? What of vegetable casein? 1044. What is said of the composition of the albuminoids?

**1046.** These substances will be noticed in their physiological relations when we consider the subject of animal nutrition. The remarkable advance in organic chemistry of late years has brought them forward into new relations, and they have received many names. They are called *protein compounds*, *nitrogenous alimentary principles*, and as one of the names of nitrogen is *azote*, they are termed *azotized* substances. As they form the materials from which the body is nourished and built up, LIEBIG named them the *plastic elements of nutrition;* they are also known as *flesh-forming* and *blood-producing* compounds.

## § II. *Putrefaction and Disinfection.*

**1047.** A leading characteristic of the foregoing substances is, as we have stated, their instability. This is due, *first*, to the presence in large proportion of the fickle element nitrogen; second, to the large number of elements combined together, and the resulting complexity of the attractions; and third, to the great number of atoms associated, or the massiveness of the molecules. When in a moist state, and exposed to atmospheric oxygen, the tottering equilibrium of the chemical fabric is overturned, and out of its ruins a new class of substances is produced. It is well known that flesh, blood, milk, dough, &c., all of which are rich in nitrogenous substances, will preserve their properties in the air only a short time, and pass into a state of decomposition, giving forth offensive exhalations. This change is called *putrefaction*, and when once commenced, it rapidly spreads through the mass, communicating itself to all putrifiable substances with which it is brought in contact.

**1048. Propagation of the Effects.**—As a spark may kindle a conflagration that shall consume a city, so the minutest amount of putrescent matter is sufficient to affect an indefinite quantity of changeable substance. The remarkable communicability of these effects and their potency of action are painfully illustrated by physicians, who sometimes wound themselves while dissecting. The small trace of decomposing matter from the dead body which clings to the dissecting knife is sufficient to establish a rapid de-

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1045. Give the origin of protein. How is it considered by different chemists? 1046. By what names are the albuminoids known? 1047. What is a leading property of these substances? To what is it due? What is putrefaction? 1048. What

composition in the living system, which, in many cases, quickly terminates in death. Another case in point is the communication of the virus of smallpox, which, when introduced into the blood, reproduces its peculiar putrefaction throughout the system.

**1049. Products.**—The chief products of putrefaction are hydrogen, nitrogen, carbonic acid, ammonia, carburetted, sulphuretted, and phosphuretted hydrogens, and acetic, nitric, and butyric acids. Other compounds also arise with the varying conditions. The gaseous combinations of sulphur and phosphorus are the chief causes of the offensive odor of putrefying bodies. In addition to these well-determined products, putrefaction gives rise to another class less tangible, but more baneful. The foul accumulations of neglected towns, and the decomposing organic matter of many swampy districts, give off invisible emanations known as *miasms* and *malaria*, which fill the air, and when inhaled, often occasion fatal fevers and epidemics. Of their composition, nature, or mode of action, nearly nothing is known.

**1050. Prevention of Putrefaction.**—As the presence of moisture, a favoring temperature, and access of air are essential conditions of putrefaction, if any of them are withdrawn, the effect is prevented. It is well known that the most perishable organic substances, both vegetable and animal, may be indefinitely preserved by drying. Cold checks decomposition, and it is entirely arrested by freezing. So, if the prime inciter of change, oxygen, is excluded, putrefaction cannot take place. This fact is illustrated by the general practice of preserving all kinds of alimentary substances, meat, fruits and vegetables, in vessels which exclude the air. It is not enough, however, to remove the oxygen from the surface of the body; that which is diffused within it must be expelled, which is done by boiling, or in some cases by a lower heat.

**1051. Antiseptics** are preventers of change—substances which act in various ways upon changeable bodies to preserve them. Common salt and saltpetre act by partial desiccation. They abstract water from the flesh, and hence concentrate the solution of

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of the action of putrescent bodies? Examples. 1049. Mention the chief products of putrefaction. To what is the odor of putrefying bodies due? What are other products of putrefaction? 1050. How is putrefaction prevented? How are organic bodies preserved? Examples. What is necessary to preservation? 1051. What are antiseptics? Explain the action of salt and saltpetre. Of alcohol and

albumen within; by surrounding the meat with salt water, and partially expelling the air, putrefaction is counteracted. Alcohol and sugar act in a similar way, removing a large portion of water from flesh and fruits, and surrounding them with unchangeable liquids and sirups, which prevent the access of oxygen.

**1052.** Other antiseptics act directly upon the albumen, coagulating and fixing it in unchangeable compounds. The sap and juices of all plants contain more or less of dissolved albumen, which, by its putrefaction, becomes an active cause of the decay of wood. Rapid drying or 'seasoning' renders the albumen inert, and the same object may be secured in less time by injecting the pores of the wood with any compound which coagulates the albumen. Wood is rendered indestructible by a process applied by Dr. KYAN, which consists in steeping it in a solution of corrosive sublimate (*kyanizing*). BOUCHERIE cut into the trunks of living trees and introduced salts of iron, which were drawn up by the sap, and, impregnating the wood, increased its durability. Dried animal bodies are preserved from change by injecting in their veins corrosive sublimate, acetate of lead, chloride of zinc, and many other substances. These, like arsenic, are poisons. As life consists in change, and these *arrest* change, they destroy life, and thus conserve the structures in which it was manifested.

**1053. Disinfectants.**—A distinction is drawn between antiseptics and disinfectants—the former *prevent* putrefaction, the latter *arrest* it; though some substances often act in both ways. Compounds rich in oxygen, and which, when mixed with putrefying matter are decomposed, act as powerful disinfectants. The permanganates perform this office, rapidly destroying the odor of putrid matter, and oxidizing sulphuretted and phosphuretted hydrogen. Nitric acid and several of the nitrates act powerfully in the same way. Fumes of nitrous acid and chlorine are efficient disinfectants. Chlorine is conveniently used in the form of chloride of lime or soda; the addition of a little sulphuric acid sets the gas free rapidly. In disinfecting rooms by fumigation with gases, it is to be remembered that they corrode all metallic surfaces. Vinegar, and especially wood vinegar, which contains a little creosote, is a valuable disinfectant. So also is sulphurous acid (fumes

sugar. 1052. Of other antiseptics. Of seasoning. What is kyanizing? Give BOUCHERIE'S experiment. How are animal bodies preserved, and why? 1053. What is a distinction between antiseptics and disinfectants? Explain the action

of burning sulphur); it destroys sulphuretted hydrogen by oxidizing it, and it also acts by absorbing oxygen. The disinfecting power of charcoal has been elsewhere noticed.

**1054. Natural Disinfectants.**—We have seen that oxygen and ozone of the atmosphere and the carbonaceous element of the earth are natural disinfectants on a vast scale. Water, although favoring decomposition, is an invaluable agent for removing and finally destroying putrescent matters, and heat, although up to 140° a promoter of putrefaction, above that point, by becoming a dryer and disorganizer, destroys the sources and products of infection.

## § III. *Fermentation.*

**1055.** When the ternary compounds, as sugar or starch, are exposed to the air, in a moist state, they exhibit but little tendency to change, and give rise to none of the effects of putrefaction. But if to a solution of sugar there be added a little putrefying flesh, blood, cheese, milk, flour paste, white of egg, or any albuminous substance in a state of decomposition, their action is communicated to the sugar, which is broken up into new compounds. When the putrefiable substances are considered with reference to the effects they produce upon the other class of bodies, they are called *ferments*, and the communication of that condition of change is known as *fermentation*.

**1056. Mode of Action of Ferment.**—When changing nitrogenous matter acts upon sugar to decompose it, there is no combination between the elements of the two substances. All that is communicated, therefore, is an *impulse of motion*. The collision of oxygen shatters the nitrogenous group; its motion is communicated to the atoms which compose the sugar, thus overturning their nicely balanced affinities. But the sugar cannot, like albuminous compounds, take the infection and go on decomposing itself. It only acts as it is acted upon, and when the motion of the impelling body is exhausted, the action ceases. Two parts by weight of ferment only decompose a hundred parts of sugar.

**1057. Vinous Fermentation.**—When the sweet juice of fruits or plants is exposed to the air at the temperature of 70° or 80°, in

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of the latter? Give examples. 1054. What are great natural disinfectants? What of water and heat? 1055. How is fermentation produced? What are ferments? 1056. State their mode of action. When does it cease? What proportion of fer-

weather. As it is less apt to become viscid than most other oils by exposure to the air, it is preferred for greasing delicate machinery. In Southern Europe it is extensively used as a substitute for butter.

**973.** Palm Oil is expressed from the fruit of the palm tree, and is of an orange-yellow color. It contains 70 per cent. of olein and 30 per cent. of a peculiar fat resembling margarin, which is termed *palmatin*. It is largely employed in the manufacture of soap and candles. The *oil of sweet almonds* is mainly used in ointments, liniments, and soaps. *Colza oil*, or *rape oil*, is obtained from the seeds of a plant belonging to the cabbage family. It is extensively employed for illumination, and is also used for lubricating machinery.

**974. Train Oil,** *or Whale Oil*, is obtained from the fat of various fishes, as the whale, dolphin, and the seal. It is of a yellow color, and not of a disagreeable odor unless the fish were putrid, or the oil expressed by a strong heat. It is used for illumination, to oil leather, in medicine, and in soap making.

**975. Spermaceti** is a solid fat which is found in the head of the sperm whale in connection with sperm oil. Pure spermaceti is a beautifully white, crystalline substance, somewhat unctuous to the touch, and resembles white wax in lustre and hardness. It is employed for making candles, and in pharmacy as an ingredient in ointments. In this fat the ordinary base glycerin is replaced by another, termed *ethal*.

**976.** Butter is the oily portion of milk, and is a mixture of several fats, the principal of which are margarin and butyrolein. Bromeis found in 100 parts of butter 68 parts of margarin, and 30 of butyrolein, the remainder being *butyrin*, *caproin*, and *caprylin*, compounds of butyric, caproic, and caprylic acids, with glycerin. The characteristic odor and flavor of butter are owing to the presence of these latter substances.

**977.** Human Fat is soft, yellowish, and without odor. Its solid constituent is principally margarin, with a proportion of palmatin and olein. The bodies of persons that have been for years buried in churchyards are sometimes found to have been changed into a peculiar substance resembling fat, and termed *adipocere*. It is also

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Give its composition and uses. 973. From what is palm oil procured? State its composition and uses. What of colza oil? 974. For what is whale oil used? 975. What of spermaceti? 976. Of what is butter composed? 977. What is

formed when the bodies of animals are exposed to running water till the muscular and membranous parts have been washed away. It has been shown that this substance is the original fat of the body, which has resisted decomposition, and is partly in the state of a fatty acid, and partly saturated by ammonia, with traces of lime and magnesia.

## § IV. *Volatile or Essential Oils.*

**978.** These differ in many particulars from the fixed oils. They readily volatilize, and are usually possessed of a strong odor and hot, pungent taste. They make only a transient stain upon paper, do not form soaps, and are all of vegetable origin. They dissolve in alcohol, ether, and acetic acids, and mix readily with the fixed oils. Their solution in alcohol is termed an essence, hence the name *essential* oils.

**979. Preparation.**—These oils are generally obtained by distilling portions of the plant with water. The steam, as it passes over, carries with it the oil, although the boiling point of many of them is higher than that of water. The water and oil condense together, most of the oil floating upon the surface. A small proportion, however, is retained in solution by the distilled water which gives it the odor and taste of the essence. These solutions are termed 'perfumed waters,' as rose water, lavender water, &c. In some cases the oil is obtained by expression directly from the cells which contain it, as from fresh orange and lemon peel. In other cases, where the oil is so delicate as to be destroyed by distillation, it is extracted by placing the plant or flower between layers of cotton, or of woollen cloth, saturated with some fixed oil. This gradually absorbs the volatile oil of the plant, and a fragrant essence is prepared by digesting the cotton in alcohol. The specific gravity of these oils varies from 0.847 to 1.17.

**980. Composition of the Volatile Oils.**—They generally contain two proximate principles, viz., *Stearopten*, the solid constituent, and *Elaopten*, which has a liquid consistence. In reference to their ultimate composition they are usually divided into three classes: 1st, those composed of carbon and hydrogen only; 2d,

the composition of human fat? What is adipocere? 978. How do volatile differ from fixed oils? Why are they so named? 979. How are they obtained? What are perfumed waters? In what ways are essential oils prepared? 980. What is their composition. How are they divided? 981. For what is the

those composed of carbon, hydrogen, and oxygen; and 3d, those which contain sulphur and nitrogen in addition to the last named.

**981.** The first class includes fifteen or twenty bodies that are remarkable for their isomerism. Thus, the oils of turpentine, lemons, oranges, juniper, copaiba, citron, black pepper, and several others which have widely different properties, possess exactly the same composition—100 parts of each containing 88.24 of carbon and 11.76 of hydrogen.

**982. Oil of Turpentine** (*Spirits of Turpentine*) may be taken as a type of this class of substances. It is obtained by distilling with water the pitchy matter that exudes from the pine tree. The portion remaining after distillation is common *rosin*. Oil of turpentine is a colorless, limpid fluid, having a strong odor and disagreeable taste. It boils at 320°, and has a specific gravity of 0.86. It is highly inflammable and when purified is used for illuminating purposes, under the name of *camphene*. *Burning fluid* is rectified turpentine, or camphene dissolved in alcohol, which increases the proportion of hydrogen and renders it less smoky when burned. Turpentine is also used in varnishes as a solvent for resins and gums. *Hydrochlorate of camphene* or *artificial camphor* is obtained by passing a current of dry chlorohydric acid through oil of turpentine. It is a white, crystalline solid, closely resembling common camphor.

**933.** The second class, or those oils containing oxygen, includes among others, common camphor, the oil of bitter almonds, and the oils of cummin, cinnamon, anise seed, peppermint, roses, lavender, &c.

**984. Camphor** is extracted by distilling the wood of the camphor tree (found in Japan and other parts of the East), with water, and collecting the vapors in a vessel containing rice straw. It condenses in the straw and is again sublimed, after which it is thrown into commerce; but it requires subsequent purifications to fit it for use. Camphor is quite volatile and readily soluble in alcohol, with which it forms a solution known as *spirits of camphor*. Taken in large doses it acts as a poison.

**985.** Black mustard seed, onions, horseradish, hops, &c., yield oils containing sulphur and belong to the third class. Many of

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first class remarkable? Examples. 982. What is oil of turpentine? Rosin? Burning fluid? Artificial camphor? 983. What does the second class include? 984. How is camphor obtained? What is spirits of camphor? 985. What is said

them are characterized by pungent, unpleasant odors, which are readily observable in the breath after eating substances containing them.

## § V. *Resinous and Waxy Compounds.*

**986.** Some plants produce in considerable quantities a substance resembling beeswax, which has the same chemical constituents as the fats and oils. The glossy coating or varnish which is observed on the surface of leaves, fruit, and bark, rendering them impermeable to water, consists of *vegetable wax*.

**987. Beeswax,** a secretion of the honey bee, is the most important of these bodies. In its ordinary state it is yellow, but is bleached white by exposing it for some time in thin ribands to the joint action of air, light, and moisture. Wax is principally used in the manufacture of candles.

**988. Resins** are supposed to be formed by the oxidation of the essential oils. They are found in most plants, and exude from many of them in the form of a more or less viscid liquid, which consists of the resin united with a portion of essential oil. The pure resins are translucent, brittle solids, insoluble in water, but soluble in alcohol, ether, and volatile oils. They are bad conductors of electricity, are highly inflammable, and burn with a smoky flame. They are of various colors, but generally brown, green, or red.

**989. Common Pine Resin**—*Colophony*—*Rosin*.—This is the residue left after the distillation of crude turpentine, and constitutes from 75 to 90 per cent. of its weight. Common rosin consists of two isomeric acids, the *sylvic* and *pinic*, which unite with bases to form salts, and with alkalies to produce soaps. An oil termed *sylvic*, or *rosin oil*, is obtained from this variety by distillation. Rosin has various uses, the most important of which are in the manufacture of a cheap varnish or coating applied to ships and in the manufacture of lamp black (534). It is also used in soldering and as a source of illuminating gas.

**990. Lac** is a resinous substance of much importance, found as an exudation on the branches of various trees in tropical coun-

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of the third class? 986. Describe vegetable wax. 987. What of beeswax? 988. What are resins, and where found? Their properties? 989. What is common rosin, and of what does it consist? Mention the uses of rosin oil and of rosin? 990. What is lac, and how formed? What is stick lac? Seed lac? Uses?

tries. The bark is punctured by an insect, thus opening a passage for the juice which, as it flows out, hardens over the insects. The twigs, when removed in this condition, constitute the *stick lac* of commerce. The resinous mass, when digested in a solution of carbonate of soda, yields a red coloring matter contained in the insects. This is largely used as a dye in the place of cochineal. The portion insoluble in the carbonate of soda is called *seed lac*, and this, when melted and purified, is *shell lac*. Lac is extensively consumed in the manufacture of varnishes and sealing wax, and also as a stiffening for hats. *Guaiacum* is a resin of a dark, greenish-brown color, and is the product of the lignum vitæ tree. It is used medicinally.

**991. Gum Resins** are the solified milky exudations of plants. They consist of resin, essential oils, and a gummy substance peculiar to the plant. They are soluble in rectified alcohol, and form a class of valuable medicinal agents. *Ammoniacum*, *assafœtida*, *aloes*, *myrrh*, *gamboge*, &c., belong to this class.

**992. Balsams.**—This name is given to the fluid compounds of resin and essential oil that exude from trees and shrubs. Among the most important are *turpentine*, *balsam copaiba*, *balsam tolu*, and *gum benzoin*. From the latter is obtained benzoic acid.

**993. Amber** is a fossil substance, sometimes occurring in beds of coal, but usually found on the shores of the Baltic Sea, where it is washed up by the waves during long storms. It is a mixture of several resinous substances, and often incloses insects in a state of beautiful preservation; hence it is supposed to be a solidified resin. It is a yellowish, translucent body, somewhat heavier than water, and has the property of becoming electric by friction. Being quite hard and susceptible of a fine polish, it is used for making ornaments.

**994. Varnishes** are solutions of various resins in alcohol, the essential oils, or the drying oils, and are employed to give lustre and hardness to exposed surfaces. When alcohol is the solvent, the product is a *spirit varnish;* when oil is used, an *oil varnish*. The resins principally used in the manufacture of varnish are mastic, sandarac, copal, lac, &c.

**995. Elastic Gums**—*Caoutchouc or India Rubber*.—This is

What is guaiacum? 991. Describe gum resins. Examples. 992. What of balsams? 993. What is amber, and where found? State its properties and use. 994. What of varnishes? 995. What is caoutchouc, and how obtained? Give its

the product of several tropical trees, from which it exudes as a yellowish, milky liquid, in which the small caoutchouc globules are mechanically suspended. The juice is spread out in films, when it rapidly dries away, leaving the caoutchouc as a thin, elastic layer of a brownish-yellow color. Or, the juice is collected in vessels and poured in successive layers over moulds, on which it is dried by artificial heat. Pure caoutchouc is nearly white, the ordinary black color of the gum being due to the smoke which arises from the fire during the drying process. The solvents of caoutchouc are pure ether, chloroform, bisulphide of carbon, coal naphtha, and rectified oil of turpentine. It melts at about 250°, but on cooling does not return to its solid state. Caoutchouc contracts on being heated, thus forming one of the exceptions to the general law of expansion by heat (251).

**996. Vulcanized India Rubber** is formed by charging caoutchouc with two or three per cent. of sulphur. The operation increases its elasticity, and also its capacity for retaining it both at high and low temperatures. It moreover increases its insolubility, and fits it for a thousand applications in the arts for which ordinary caoutchouc would be unsuitable. The addition of magnesia and some bituminous matter to vulcanized rubber, gives it a high degree of hardness, and renders it susceptible of a fine polish, but in a great measure destroys its elasticity. In this state it is largely used in the manufacture of combs, knife handles, and various ornamental articles. Caoutchouc, from the cohesiveness of its freshly cut edges, its elasticity, pliancy, and power of resisting most chemical agents, is of great use in the laboratory. If a piece of sheet rubber be wrapped over a glass rod, Fig. 275, on pressing together its freshly cut edges with a gentle heat, they will unite, forming a flexible tube which, on being tightly tied over two glass tubes, will serve to connect them together gas-tight.

FIG. 275.

Cohesion of Caoutchouc.

**997. Gutta Percha** is a substance resembling caoutchouc, and

properties. Its solvents. To what is it an exception? 996. How is vulcanized india rubber made? What is the change effected? How is it rendered still harder? For what used? Why is caoutchouc useful to the chemist? Describe Fig. 275. 997. What is gutta percha, and how obtained? Give its properties. Its uses. 998.

obtained from plants in the same form of milky exudation. Under ordinary circumstances it is a tough, hard, unelastic body, insoluble in water or alcohol, but soluble in chloroform, bisulphide of carbon, turpentine, and most of the essential oils. Immersed in warm water, it becomes soft and plastic, and admits of being moulded in any desired form, retaining its shape on being cooled. In consequence of this property it is used in taking casts and impressions, copying the finest lines with fidelity. It is also readily welded while in this waxy condition. It is of a pale brown color, is an insulator of electricity, and becomes negatively electric by friction.

## § VI. *Action of Alkalies upon Oils—Soap.*

**998. Saponification.**—It was stated that the oils and fats are saline bodies, consisting of fatty acids combined with a common base, *glycerin*. When other bases, as potash, soda or ammonia, are made to act upon the fatty substances, they expel the glycerin and take its place, uniting with the acids and forming *soap*. Soaps are therefore regular salts; combinations of margaric, stearic and oleic acids with potash, soda, ammonia, or lime. The change by which they are produced is called *saponification*.

**999. Process of Soap Making.**—The alkalies generally used for soap making are potash and soda. They require to be in a caustic state, which is produced by dissolving them and passing the solution (lye) through newly slacked lime, which takes away the carbonic acid. In this caustic lye, the fats are boiled, their glycerin set free, and the soap formed in a state of solution in the water. To obtain it in a solid form the solution is boiled down till the soap ceases to be soluble and rises to the surface, when it is drawn off into moulds. Soda soap may be separated from the water in which it is dissolved by adding common salt, which forms a brine and at once coagulates the soap; if potash lye is used, the addition of salt decomposes the potash soap, forming a soda soap, and chloride of potassium.

**1000. Hard and Soft Soaps.**—The consistence of soap depends chiefly upon its alkali. Hard soaps are made of soda, or a mixture of soda and potash, while in soft soaps potash alone is used,

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How is soap produced? What is saponification? 999. Name the alkalies used. Describe soap making. How may soap be separated from the water? 1000. How do hard and soft soaps differ? 1001. What is castile soap? Cocoa soap.

the latter alkali being deliquescent and consequently attracting water, which renders the soap liquid. The consistence of the oil or fat also influences the quality of hardness. Those containing a large proportion of stearin and margarin, like tallow, form hard soaps, while those in which olein predominates, as the soft fats and oils, produce soft soap. The glycerin which is retained in soft soap also adds to its fluidity.

**1001. Castile Soap** is composed of olive oil and soda, its mottled appearance being due to the oxide of iron, with which it is colored. Soap made with cocoanut oil has the property of dissolving in salt water, and is therefore used at sea.

**1002. Properties.**—Soap has a powerful affinity for water and may retain from 50 to 60 per cent. of it and still continue solid; hence dealers generally keep it in damp places where it will absorb moisture. It is soluble in fresh water, but with the exception of cocoa soap, is insoluble in salt water. Soap dissolved in spirits of camphor, forms *opedildoc*. *Volatile liniment* is an ammoniacal soap.

**1003. Mode in which Soap acts in Cleansing.**—As water, having no affinity for oily substances, will not dissolve them, of course it cannot alone remove them from surfaces to which they may adhere. The oily matters which are constantly exuding from the glands of the skin, uniting with the outer dust, form a film over the body. The alkali of the soap acts upon the oil during ablution, partially saponifies it, and renders the unctuous compound freely miscible with water, so as to be easily removed. The cuticle or outer layer of the skin is chiefly composed of albumen, which is soluble in the alkalies. The alkali of the soap, therefore, dissolves off a portion of the cuticle with the dirt; every washing with soap thus removing the old face of the scarf-skin and leaving a new one in its place. The action of soap in cleansing textile fabrics is of a similar nature. Alkalies not only act upon greasy matter, but as is well known, dissolve all organic substances. In the case of soap, however, the solvent power of the alkali is in part neutralized, thus preserving both the texture and color of the fabric exposed to its action. The oily nature of the soap also increases the pliancy of the articles with which it is washed.

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1002. What of soap in relation to water? What is opedildoc? Volatile liniment? 1003. How does soap act in cleansing? Explain its action upon the skin. Upon textile fabrics. 1004. What of washing fluids? Of camphene? 1005. Where and in

**1004.** Solutions of the alkalies under the name of *washing fluids* are often used in cleansing textile fabrics. They act by precipitating whatever earthy salts the water may contain, thereby rendering it soft, and supplying an excess of alkali. Camphene, which has the property of dissolving oily substances without injuring the fabric, is sometimes employed as a detergent.

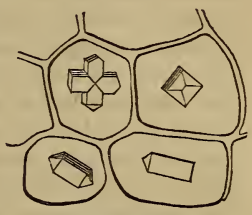
# CHAPTER XXI.

## ORGANIC ACIDS, BASES, AND COLORING PRINCIPLES.

### § I. *Vegetable Acids.*

**1005.** These substances are numerous in the vegetable kingdom, occurring abundantly in fruits, and often in the leaves, bark, and roots of plants. They exist in a free state, and combined with bases, forming acid and neutral salts, both soluble and insoluble. They sometimes accumulate in the cells of plants in the form of crystals, of which Fig. 276 is an example from the cells of an onion.

FIG. 276.



Crystals in Cells.

**1006.** They usually consist of carbon, hydrogen, and oxygen, the latter element being greatly in excess. Oxalic acid, however, contains only carbon and oxygen, and in acetic acid the hydrogen and oxygen are in the proportion to form water. Some of these acids have been described in connection with groups to which they naturally belong, while the mode of their production is treated in Physiological Chemistry. We shall consider here a few others of the most important.

**1007. Tartaric Acid,** $C_3H_4O_{10}, 2HO$.—This acid is found abundantly in grapes, and is also present in the tamarind, the unripe berries of the mountain ash, and in small quantity in other plants. It exists in grape juice as bitartrate of potash (*cream of*

what state are organic acids found? Of what is Fig. 276 an example? 1006. What is said of their composition? 1007. Where is tartaric acid found, and how ob-

*tartar*), and is gradually deposited in the form of a hard crust on the sides of vessels in which wine is kept. From this bitartrate, it is obtained by the action of chalk and sulphuric acid. Its crystals, when pure, are colorless, transparent, permanent in the air, and dissolve readily in water or alcohol. It is extensively used by the calico printer and dyer for the removal of mordants. Mixed with bicarbonates of the alkalies, it forms the soda powders of the effervescing draughts.

1008. **Rochelle Salt** is a tartrate of potash and soda, produced by saturating a solution of cream of tartar with soda. *Tartar emetic*, or tartrate of antimony and potash, long used medicinally, is a violent emetic and cathartic poison.

1009. **Citric Acid,** $C_{12}H_5O_{11}$, 3HO, is found principally in fruits of the orange family (*Aurantiacæ*), but is of frequent occurrence in gooseberries, currants, and other acid fruits. It may be readily procured from the juice of the lemon by the aid of chalk and sulphuric acid. It has a pleasant acid taste, is very soluble in water, and is used in medicine, calico printing, and for effervescing draughts.

1010. **Malic Acid,** $C_3H_4O_3$, 2HO, is the principal acid of unripe apples, hence its name from *malus*, apple. It is found abundantly in most acid fruits, and in the stalks of rhubarb, but is usually obtained from the unripe berries of the mountain ash. It is a colorless solid, dissolves readily in water and alcohol, and crystallizes with difficulty. The solutions of all the acids named have an agreeable acid taste, but become mouldy if long kept, and gradually undergo decomposition.

1011. **Oxalic Acid,** $C_2O_3$,HO.—This substance imparts the acid taste to common sorrel and the rhubarb plant, in which it exists as binoxalate of potash. In the barilla plant it is found as oxalate of soda, and in many lichens as oxalate of lime. It is commonly prepared by the oxidation of sugar or starch with nitric acid: 1 part of sugar is dissolved in 8 parts of nitric acid, and gently heated, when intense action ensues, with a copious disengagement of nitrous acid fumes. The crystals obtained are intensely sour and poisonous, and resemble Epsom salts, for which they are sometimes mistaken. In cases of poisoning with

tained? State its appearance and uses. 1008. What is Rochelle salt? Tartar emetic? 1009. Give the origin and properties of citric acid. 1010. Of malic. 1011. Give the composition of oxalic acid. Where is it found, and how procured?

it, chalk or magnesia, suspended in water, is the proper antidote.

**1012.** Oxalic acid is largely used in calico printing, and it is also employed as a delicate test for the presence of lime, with which it forms an insoluble salt. It removes ink and iron stains from linen by forming a soluble oxalate of iron, but the acid is so corrosive as to injure the fibre if not immediately removed by washing.

**1013. Tannic Acid,** $C_{54}H_{22}O_{34}$.—There are several distinct compounds known under the name *tannin*, which resemble each other in character and possess an acid reaction. They are found extensively diffused throughout the vegetable kingdom, and are all distinguished by an astringent taste. The bark and leaves of most forest trees, as well as of many fruit trees, contain a large quantity of tannin, and it is also found in various roots, shrubs, and seeds. Tannin is the astringent principle of tea and coffee.

**1014.** The most important of these compounds is that obtained from gall nuts—the *gallotannic acid.* It has an intensely astringent taste, reddens litmus paper, and is very soluble in water. Tannic acid combines with the salts of the peroxide of iron, forming a blue-black precipitate used for coloring, and also in the manufacture of writing ink. The gradual darkening of pale watery ink is due to the oxidation of the iron it contains. Tannin forms insoluble compounds with starch, gelatin, and other organic bodies, the most remarkable being that with gelatin, which is the basis of leather.

**1015. Gallic Acid** is found associated with tannin in the gall nut, sumach, and other vegetable bodies, and is formed from tannic acid by exposing a solution of it for some time to the air. It crystallizes in silky needles, is freely soluble in boiling water, and does not precipitate gelatin. On applying a regulated sand heat, gallic acid is decomposed and *pyrogallic acid* obtained. This acid is extensively used in photography. Both pyrogallic and gallic acids decompose the salts of silver, gold, and platinum; a property which is utilized in coloring human hair. The hair is first wet with a solution of gallic acid, and after drying, is moistened with an ammoniacal solution of a salt of silver. The salt is

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What of its crystals and the antidote? 1012. What is said of its uses? 1013. Where are the compounds of tannin found? 1014. What is the most important? Give its properties. Uses. To what is the darkening of ink due? What compounds does tannin form? 1015. How is gallic acid obtained? Pyrogallic? For what

decomposed and the liberated metal dyes the hair of a fine and permanent black or brown.

1016. There are many other vegetable acids yet imperfectly known, and many more the results of natural and artificial decomposition; but they are not of sufficient importance to be here noticed.

## § II. *The Organic Bases.*

1017. **The Vegetable Alkaloids or Organic Bases** are an important natural group of substances, chiefly formed in vegetables and giving to them their active properties. They are always found in the form of salts, and usually in combination with an organic acid. Nitrogen is an invariable element of the alkaloids, but some of them contain no oxygen. Those destitute of oxygen are oily, volatile bodies obtained by distillation, and as they absorb oxygen rapidly from the air, they are produced in a current of hydrogen, or carbonic acid. Those which contain oxygen are prepared by dissolving the vegetable matter in dilute chlorohydric or sulphuric acid, which forms a soluble salt with the alkaloid. To the filtered solution a stronger base is added—such as lime, ammonia, or magnesia, which produces a copious precipitation of the alkaloid.

1018. **Properties.**—These bodies dissolve sparingly in water, but freely in boiling alcohol, are intensely bitter, and usually restore the reddened color of litmus. They are the most powerful medicines and poisons known. Gallotannic acid precipitates most of the organic bases, forming insoluble compounds; hence it is an excellent antidote to them when they have been taken in poisonous doses. We shall notice only the more important alkaloids found in vegetable substances.

1019. **Quinia,** $C_{40}H_{24}N_2O_4+6Aq.$—*Quinine* is extracted from pulverized Peruvian bark by acidulated water. It is a white, crystalline substance, which unites with acids, producing intensely bitter salts. The sulphate of quinine, which forms light, bulky crystals, is the salt employed in medicine. It dissolves sparingly in water, but freely in dilute sulphuric acid and alcohol. *Cinchonine* is an analogous alkaloid from the same source.

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are they used? How do they color the hair? 1017. What is said of the organic bases? What of those destitute of oxygen? How are those containing oxygen prepared? 1018. Mention the properties of these bodies. What is the effect on them of gallotannic acid? 1019. Give the origin and properties of quinia.

**1020. Nicotine,** $C_{10}H_7N_1$, a volatile alkaloid, is the active principle of the tobacco plant. It is a colorless, inflammable, oily liquid, with a powerful and irritating odor of tobacco. It is contained in the smoke of the burning leaves and is exceedingly poisonous, a single drop being sufficient to kill a large dog.

**1021. Morphia,** $C_{34}H_{19}NO_6+2Aq$.—*Morphine* is the active principle of opium, which is the hardened, milky juice of the poppy. Opium is a very complex body, containing no less than seven organic bases and several other well-defined principles. *Morphine* (from Morpheus, in consequence of its sleep-inducing property) is a crystallizable, resin-like body, without odor, and possessing a bitter, disagreeable taste. It is a powerful narcotic and poison, largely used in medicine.

**1022. Strychnia,** $C_{42}H_{22}N_2O_4$.—*Strychnine* is chiefly obtained from the beans of the *strychnos nux vomica*, a small East Indian tree, but is found in several other plants belonging to that tribe. Cold water dissolves only $\frac{1}{7000}$ of its weight of strychnine, but it is soluble in essential oils and chloroform. Such is its intense bitterness that it imparts it perceptibly to 700,000 times its weight of water. It is a deadly poison, $\frac{1}{30}$ of a grain killing a dog in 30 seconds. It takes effect upon the nerve centres of the spinal axis, producing fearful convulsions. The terrible *woorara* poison, with which the South American natives poison their arrows, and which has been lately used as a remedy for *tetanus*, is a variety of strychnine. So also is the poison of the upas tree of Java. *Brucia* is an alkaloid closely allied to strychnine and obtained from the same genus of plants.

**1023.** Common lettuce has slight narcotic properties, which are due to an alkaloid, *lactucine*. In the same way *conicine* is extracted from the hemlock; *aconitine*, or *aconite*, from the monk's hood; *solanine* from potato sprouts; *piperine* from black pepper, and *emetine* from ipecacuanha.

**1024. Caffeine or Theine,** $C_{16}H_{10}N_4O_4+2$ Aq.—The active principle of coffee, *caffeine*, and of tea, *theine*, as also of the *mate* or Paraguay tea, are identical in composition. It is interesting to observe that the plants which have been selected to furnish

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1020. What of nicotine? 1021. Describe morphia. Its properties. 1022. Where is strychnia found? State its properties. What of the woorara and upas poisons? What is brucia? 1023. Mention some other vegetable alkaloids. 1024. Give the composition of theine. What is an interesting fact regarding this principle? State

infusions for the daily beverage of three fourths of the human race should contain one and the same nitrogenized principle. *Theobromine*, the active constituent of chocolate, is also nearly allied to caffeine. Coffee seldom contains more than one per cent. of the principle, while tea furnishes three or four. Caffeine crystallizes in long, flexible, silky needles, has a slightly bitter taste, and dissolves sparingly in cold water, but freely in hot water.

**1025.** Tea consists of four principal constituents. *First*, a yellow volatile oil, which produces its peculiar aromatic odor and flavor. It does not exist in the natural leaves, but is produced by the roasting process to which they are subjected. Tea yields but 1 per cent. of this oil. *Second*, theine. *Third*, tannic acid, which forms from 12 to 18 per cent. of its weight, and gives to tea its astringent properties. *Fourth*, tea leaves contain some 15 per cent. of an insoluble, glutinous substance, which is lost with the 'grounds.'

**1026.** The varieties of tea are numerous, depending upon soil, climate, time of picking the leaves, and the modes of their preparation. *Green tea* is prepared from the young leaves, which are roasted and withered almost immediately after they have been gathered. They are then rolled in the hand, by which they acquire their twisted appearance, and quickly dried, sifted, and winnowed; the whole operation being brief and simple. Black tea, on the contrary, upon being gathered, is exposed to the air for ten or twelve hours. It is then roasted, a large quantity of liquid expressed from it, and after several alternate rollings, roastings, and exposures to the air, it is slowly dried over a charcoal fire. The dark color of black teas is mainly owing to the action of oxygen upon the juices during the long exposure of the leaves.

**1027. Constituents of Coffee.**—Besides its caffeine, the coffee berries contain a considerable proportion of gluten, 5 per cent. of *caffeic acid*, and 14 or 15 per cent. of a fixed oil. An aromatic flavoring oil is developed during roasting, but according to PAYEN it does not exceed the $\frac{1}{3000}$ part of the weight of coffee.

## §III. *Organic Coloring Principles.*

**1028.** As a class, vegetable coloring matters do not possess many chemical characters in common, and are associated together

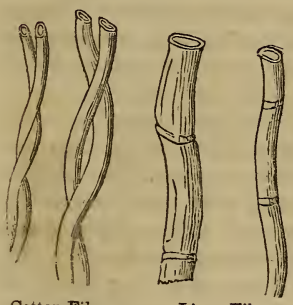
its proportion in tea and coffee. Its properties. 1025. Of what does tea consist? 1026. What occasions the varieties of tea? How is green tea prepared? Black tea? To what is its dark color owing? 1027. What are the constituents of coffee?

on account of their common applications in the arts. Some are acid, others neutral; some ternary, others quaternary. The most brilliant of vegetable colors, those of flowers, are fugitive, small in quantity, and difficult to separate. The coloring matters in the interior of plants, where they are not exposed to light, are less brilliant, but more durable. The coloring matters of plants are chiefly blue, yellow, and red; no genuine black having been obtained from them.

**1029. Dyeing.**—The art of the dyer consists in impregnating textile fabrics with the various coloring matters in such a way that they will remain permanent, or *fast*, under wear and washing. Some coloring substances, as indigo for example, unite directly with the fibres, producing fixed or *substantive* colors. Others, those chiefly which are soluble in water, do not adhere; they therefore require some intermediate substance which has an affinity for both the coloring matter and the fibre, and will bind them together in an insoluble compound. Such a substance is called a *mordant*, from the latin *mordeo*, to bite, because it was supposed to bite in the colors. Dyes which require a mordant are called *adjective* colors, and nearly all vegetable colors are of this kind.

**1030.** The principal mordants are salts of tin, iron, and alumi-

Fig. 277.



Cotton Fibres. Linen Fibres.

Fig. 278.

Woollen Fibres.

na, which not only fasten the colors, but so change them that one dye stuff gives different colors with different mordants. The tex-

1028. What is said of the permanence of vegetable colors? 1029. In what does dyeing consist? What are substantive colors? Mordants? Adjective colors? 1030. What of the principal mordants? 1031. Describe the process of calico

tile fibres consist of hollow tubes, Figs. 277 and 278, which the mordant is supposed to enter, filling them like lungs, and thus facilitating the chemical action.

**1031. Calico Printing.**—In this operation the bleached and prepared goods are printed *with the mordants* by patterns upon blocks or cylinders. As the cloth is subsequently passed through the dye, the coloring matter is fixed upon those parts where the mordant was applied. When the fabric is afterward washed, the color disappears from the other portions of the goods, and the printed figure appears.

**1032. Blue Coloring Matters.**—Indigo is obtained from the juices of a large number of East India and American plants, the principal of which belong to the genus *indigofera*. This juice is colorless, but when exposed to the air it absorbs oxygen, and deposits a blue sediment which, in the form of a powder or cakes, is known as commercial indigo. It is nearly insoluble in all liquids except sulphuric acid, with which it combines, forming *sulphindigotic acid*. When deoxidized, indigo becomes colorless and soluble in water, but on exposure to the air it again absorbs oxygen, and acquires insolubility and its deep blue color. Fabrics may therefore be steeped in a solution of colorless indigo, and on exposure to the air acquire a bright and permanent blue tint. If goods are boiled in sulphindigotic acid, a still brighter color (*Saxon blue*) is produced.

**1033.** Litmus is obtained from several species of lichens, which are destitute of color. The product is at first purple, or red, but is changed to blue by the action of the ammonia used in its preparation.

**1034. Red Coloring Matters.**—*Madder.*—The roots of the madder plant, ground to powder, furnish this valuable dye stuff. It is at first yellow, but reddens by exposure to air and absorption of oxygen. In addition to red, madder furnishes purple, yellow, orange, and brown. *Brazil wood* and *sandal wood* produce red coloring matters, and the flowers of the red saffron yield *safflower*. *Carmine* is contained in a species of Mexican cactus, and is obtained from the cochineal, an insect which feeds upon that plant. It affords a brilliant red and purple dye.

**1035. Yellow Coloring Matters.**—Among the principal of

printing. 1032. How is indigo obtained? What is sulphindigotic acid? Explain the action of indigo upon fabrics. 1033. What of litmus? 1034. What is madder? Mention other red dyes. 1035. What are the principal yellow dyes? 1036. What

these are *quercitron*, from the bark of the black oak; *fustic*, from the wood of the West Indian mulberry, and *weld*, from the *reseda luteola*. *Annotto*, used in dyeing nankeen, and also to color butter and cheese, is extracted from certain seeds grown in South America. *Turmeric* is obtained from the roots of an East Indian plant.

**1036. Chlorophyll** (*Leaf-green*) is the substance to which the vegetable world owes its uniform green color. It is of a resinous nature, soluble in alcohol and acids, but insoluble in water. Fig. 279 shows the grains of chlorophyll and needle-like crystals in the cells of a leaf. It exists only in minute quantity in plants, the leaves of a large tree, according to Berzelius, containing perhaps not more than 100 grains.

Fig. 279.

Chlorophyll in Cells.

This substance appears to be a direct product of the action of the sunbeam upon vegetation, as it is never seen except in those parts exposed to the light. Plants removed from a dark cellar into the sunlight turn rapidly of a green color, and every one may have remarked in spring how quickly, after a few days of cloudy weather, the unfolding vegetation is changed to a deep green by the rays of the sun. The change from green to red and yellow in the autumn leaves, is supposed to be owing to the oxidation of their chlorophyll.

**1037. Extractive Matter.**—This term has been applied to numerous substances, chiefly vegetable, extracted by chemists, which have not yet been accurately examined. The number of known plants exceeds a hundred thousand, and each possesses peculiar principles in small quantity to which its flavor and medicinal properties are due. Of this vast number, but few comparatively have been studied by chemists, who designate whatever of this kind that is unknown as *extractive matter*.

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is chlorophyll? Why is it thought to be a direct product of the sunbeam? What of the change in autumn leaves? 1037. What does the term extractive matter

# CHAPTER XXII.

## NITROGENOUS COMPOUNDS—THEIR CHANGES AND EFFECTS.

### § I. *The Albuminous Compounds.*

**1038.** The substances now to be noticed differ in very important respects from those hitherto considered. They have more elements; they contain nitrogen in higher proportions, have a larger number of atoms, and are therefore more complex and prone to change. They do not crystallize, and are highly organized. Though originating in the vegetable kingdom, they furnish the basis of the structures of all animal systems. The group comprises albumen, fibrin, casein, and their several modifications, and is hence called the *albuminous* or *albuminoid* group.

**1039. Albumen.**—We are most familiar with this body in the form of white of eggs, a glairy, insipid fluid, which coagulates by heat, producing a white solid; hence its name, from *albus*, white. Albumen forms about 7 per cent. of the blood, and is found in variable proportions in all the secretions of the body. It also exists dissolved in the juices of plants, or dried in their seeds. When the water which has been used to wash starch from wheat flour or scraped potatoes, is allowed to stand until it becomes clear, and is then boiled, it assumes a turbid appearance, and deposits a flaky-white substance, which has the same character as white of egg, and is known as *vegetable albumen*. When dried it forms a brittle, yellow, gummy mass, which dissolves in cold water; but when *coagulated* it will not dissolve in water, either cold or hot. The change of coagulation does not alter its composition. The temperature at which it takes place varies; a strong solution of albumen in water becomes completely insoluble at 145°, and separates in flakes at 167°. The more it is diluted with water, the higher the temperature of coagulation.

**1040. Chemical Properties.**—Albumen consists of carbon, oxygen, hydrogen, and nitrogen—some 16 per cent. of the latter—and a small but definite proportion of sulphur and phosphorus.

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signify? 1038. How do the nitrogenous compounds differ from those hitherto considered? What does the albuminous group comprise? 1039. What is the most familiar form of albumen? Where is it found? What is vegetable albumen? Its properties? 1040. Give the composition of albumen. For what is it an

Its exact composition, however, is not determined. It is coagulated by many substances, as alcohol, strong acids, creosote, and corrosive sublimate; therefore, in poisoning by these bodies, if the white of eggs be promptly swallowed, it seizes upon the noxious compounds and protects the stomach. Albumen, like water, seems capable of combining with both acids and bases. Alkalies render it soluble. White of egg and blood are both slightly alkaline, from the presence of soda; the albumen being supposed to exist as *albuminate of soda*. It forms also definite compounds with the acids. *Vitellin* is the albumen of the yolk of eggs.

**1041. Fibrin** is the name given to the substance which forms the basis or *fibre* of muscular tissue. It occurs in bundles, as shown in Fig. 280, the parallel fibres having wrinkles or cross markings. If a piece of lean beef be long washed in clean water, its red color, which is due to blood, gradually disappears, and a mass of white, fibrous tissue remains which is known as *animal fibrin*. Like albumen, it is capable of existing in two states: the soluble and the insoluble. In its soluble form it is a constituent of blood, forming in the healthy state about 2 parts in 1000 parts of that liquid. The clotting of blood, when freshly drawn, is due to the coagulation of its fibrin, which solidifies into a network of fibres. Dilute solutions of potash and soda dissolve fibrin, as they do albumen.

FIG. 280.

Fibres of lean Meat, magnified.

**1042. Gluten**—*Vegetable Fibrin.*—When wheat flour is made into a dough and then kneaded on a sieve or piece of muslin under a stream of water, its starch is washed away and there remains a gray, tough, elastic substance, almost resembling animal skin in appearance. When dried it has a glue-like aspect, and is therefore called *gluten*. The crude gluten thus prepared, when freed from oil, albumen, &c., proves to be identical in composition with animal fibrin, and is hence named *vegetable fibrin*. Like muscle fibrin, it is soluble in very dilute chlorohydric acid.

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antidote? Its chemical properties? 1041. Describe animal fibrin. What is its relation to blood? 1042. How may gluten be procured? Why is it called vegetable

**1043. Casein** is an essential constituent of milk, existing in it to the extent of about 3 per cent., and forming its curd, or cheesy principle. Its soluble form in milk is due to a small portion of free alkali, and when this is neutralized by an acid, the casein is precipitated, or the milk *curdles*. By neutralizing the acid, the casein is re-dissolved. The water in which flour has been washed contains a small portion of a substance, which is coagulated by acids; it resembles the curd of milk, and is called *vegetable casein*. It is found in large proportion in peas and beans. The Chinese make a cheese from peas which gradually acquires the smell and taste of milk cheese.

**1044. Chemical Composition.**—There is a remarkable identity in composition among the members of this group. The analysis of albumen from the hen's egg gives carbon 53.5, hydrogen 7, nitrogen 15.5, oxygen 22, sulphur 1.6, phosphorus 0.4; and, with slight variations in the proportions of sulphur and phosphorus, this may represent the composition of the whole group. LIEBIG gives the following formula as the best approximation yet obtained toward their composition:

| | |
|---|---|
| Albumen of blood, Albumen of flesh, Fibrin of flesh, | $C_{216}\ H_{169}\ O_{68}\ N_{27}\ S_2$ |
| Albumen of eggs, | $C_{216}\ H_{169}\ O_{68}\ N_{27}\ S_3$ |
| Casein, | $C_{288}\ H_{228}\ O_{90}\ N_{36}\ S_2$ |
| Fibrin of blood, | $C_{288}\ H_{228}\ O_{92}\ N_{40}\ S_2$ |

An important fact concerning these compounds is that they are physiologically isomeric—are convertible into each other in the animal system.

**1045. Protein.**—When these albuminoids are dissolved in a solution of potash or soda by a gentle heat, if an acid be added, a grayish precipitate is formed, which is attended with the liberation of sulphur and phosphorus in the form of sulphuretted hydrogen and phosphoric acid. MULDER calls this substance *protein*, and he and many other chemists regard it as the radicle or base of the whole group. They hold it to contain neither sulphur nor phosphorus, and suppose the different albuminous bodies to be formed by combinations of protein with these elements and oxygen. LIEBIG and his adherents deny that any such radicle has ever been freed from sulphur, and reject the doctrine of protein altogether.

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fibrin? 1043. Describe casein. What occasions the curdling of milk? What of vegetable casein? 1044. What is said of the composition of the albuminoids?

**1046.** These substances will be noticed in their physiological relations when we consider the subject of animal nutrition. The remarkable advance in organic chemistry of late years has brought them forward into new relations, and they have received many names. They are called *protein compounds*, *nitrogenous alimentary principles*, and as one of the names of nitrogen is *azote*, they are termed *azotized* substances. As they form the materials from which the body is nourished and built up, LIEBIG named them the *plastic elements of nutrition;* they are also known as *flesh-forming* and *blood-producing* compounds.

## § II. *Putrefaction and Disinfection.*

**1047.** A leading characteristic of the foregoing substances is, as we have stated, their instability. This is due, *first*, to the presence in large proportion of the fickle element nitrogen; second, to the large number of elements combined together, and the resulting complexity of the attractions; and third, to the great number of atoms associated, or the massiveness of the molecules. When in a moist state, and exposed to atmospheric oxygen, the tottering equilibrium of the chemical fabric is overturned, and out of its ruins a new class of substances is produced. It is well known that flesh, blood, milk, dough, &c., all of which are rich in nitrogenous substances, will preserve their properties in the air only a short time, and pass into a state of decomposition, giving forth offensive exhalations. This change is called *putrefaction*, and when once commenced, it rapidly spreads through the mass, communicating itself to all putrifiable substances with which it is brought in contact.

**1048. Propagation of the Effects.**—As a spark may kindle a conflagration that shall consume a city, so the minutest amount of putrescent matter is sufficient to affect an indefinite quantity of changeable substance. The remarkable communicability of these effects and their potency of action are painfully illustrated by physicians, who sometimes wound themselves while dissecting. The small trace of decomposing matter from the dead body which clings to the dissecting knife is sufficient to establish a rapid de-

1045. Give the origin of protein. How is it considered by different chemists? 1046. By what names are the albuminoids known? 1047. What is a leading property of these substances? To what is it due? What is putrefaction? 1048. What

composition in the living system, which, in many cases, quickly terminates in death. Another case in point is the communication of the virus of smallpox, which, when introduced into the blood, reproduces its peculiar putrefaction throughout the system.

**1049. Products.**—The chief products of putrefaction are hydrogen, nitrogen, carbonic acid, ammonia, carburetted, sulphuretted, and phosphuretted hydrogens, and acetic, nitric, and butyric acids. Other compounds also arise with the varying conditions. The gaseous combinations of sulphur and phosphorus are the chief causes of the offensive odor of putrefying bodies. In addition to these well-determined products, putrefaction gives rise to another class less tangible, but more baneful. The foul accumulations of neglected towns, and the decomposing organic matter of many swampy districts, give off invisible emanations known as *miasms* and *malaria*, which fill the air, and when inhaled, often occasion fatal fevers and epidemics. Of their composition, nature, or mode of action, nearly nothing is known.

**1050. Prevention of Putrefaction.**—As the presence of moisture, a favoring temperature, and access of air are essential conditions of putrefaction, if any of them are withdrawn, the effect is prevented. It is well known that the most perishable organic substances, both vegetable and animal, may be indefinitely preserved by drying. Cold checks decomposition, and it is entirely arrested by freezing. So, if the prime inciter of change, oxygen, is excluded, putrefaction cannot take place. This fact is illustrated by the general practice of preserving all kinds of alimentary substances, meat, fruits and vegetables, in vessels which exclude the air. It is not enough, however, to remove the oxygen from the surface of the body; that which is diffused within it must be expelled, which is done by boiling, or in some cases by a lower heat.

**1051. Antiseptics** are preventers of change—substances which act in various ways upon changeable bodies to preserve them. Common salt and saltpetre act by partial desiccation. They abstract water from the flesh, and hence concentrate the solution of

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of the action of putrescent bodies? Examples. 1049. Mention the chief products of putrefaction. To what is the odor of putrefying bodies due? What are other products of putrefaction? 1050. How is putrefaction prevented? How are organic bodies preserved? Examples. What is necessary to preservation? 1051. What are antiseptics? Explain the action of salt and saltpetre. Of alcohol and

albumen within; by surrounding the meat with salt water, and partially expelling the air, putrefaction is counteracted. Alcohol and sugar act in a similar way, removing a large portion of water from flesh and fruits, and surrounding them with unchangeable liquids and sirups, which prevent the access of oxygen.

**1052.** Other antiseptics act directly upon the albumen, coagulating and fixing it in unchangeable compounds. The sap and juices of all plants contain more or less of dissolved albumen, which, by its putrefaction, becomes an active cause of the decay of wood. Rapid drying or 'seasoning' renders the albumen inert, and the same object may be secured in less time by injecting the pores of the wood with any compound which coagulates the albumen. Wood is rendered indestructible by a process applied by Dr. KYAN, which consists in steeping it in a solution of corrosive sublimate (*kyanizing*). BOUCHERIE cut into the trunks of living trees and introduced salts of iron, which were drawn up by the sap, and, impregnating the wood, increased its durability. Dried animal bodies are preserved from change by injecting in their veins corrosive sublimate, acetate of lead, chloride of zinc, and many other substances. These, like arsenic, are poisons. As life consists in change, and these *arrest* change, they destroy life, and thus conserve the structures in which it was manifested.

**1053. Disinfectants.**—A distinction is drawn between antiseptics and disinfectants—the former *prevent* putrefaction, the latter *arrest* it; though some substances often act in both ways. Compounds rich in oxygen, and which, when mixed with putrefying matter are decomposed, act as powerful disinfectants. The permanganates perform this office, rapidly destroying the odor of putrid matter, and oxidizing sulphuretted and phosphuretted hydrogen. Nitric acid and several of the nitrates act powerfully in the same way. Fumes of nitrous acid and chlorine are efficient disinfectants. Chlorine is conveniently used in the form of chloride of lime or soda; the addition of a little sulphuric acid sets the gas free rapidly. In disinfecting rooms by fumigation with gases, it is to be remembered that they corrode all metallic surfaces. Vinegar, and especially wood vinegar, which contains a little creosote, is a valuable disinfectant. So also is sulphurous acid (fumes

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sugar. 1052. Of other antiseptics. Of seasoning. What is kyanizing? Give BOUCHERIE'S experiment. How are animal bodies preserved, and why? 1053. What is a distinction between antiseptics and disinfectants? Explain the action

of burning sulphur); it destroys sulphuretted hydrogen by oxidizing it, and it also acts by absorbing oxygen. The disinfecting power of charcoal has been elsewhere noticed.

**1054. Natural Disinfectants.**—We have seen that oxygen and ozone of the atmosphere and the carbonaceous element of the earth are natural disinfectants on a vast scale. Water, although favoring decomposition, is an invaluable agent for removing and finally destroying putrescent matters, and heat, although up to 140° a promoter of putrefaction, above that point, by becoming a dryer and disorganizer, destroys the sources and products of infection.

## § III. *Fermentation.*

**1055.** When the ternary compounds, as sugar or starch, are exposed to the air, in a moist state, they exhibit but little tendency to change, and give rise to none of the effects of putrefaction. But if to a solution of sugar there be added a little putrefying flesh, blood, cheese, milk, flour paste, white of egg, or any albuminous substance in a state of decomposition, their action is communicated to the sugar, which is broken up into new compounds. When the putrefiable substances are considered with reference to the effects they produce upon the other class of bodies, they are called *ferments*, and the communication of that condition of change is known as *fermentation.*

**1056. Mode of Action of Ferment.**—When changing nitrogenous matter acts upon sugar to decompose it, there is no combination between the elements of the two substances. All that is communicated, therefore, is an *impulse of motion.* The collision of oxygen shatters the nitrogenous group; its motion is communicated to the atoms which compose the sugar, thus overturning their nicely balanced affinities. But the sugar cannot, like albuminous compounds, take the infection and go on decomposing itself. It only acts as it is acted upon, and when the motion of the impelling body is exhausted, the action ceases. Two parts by weight of ferment only decompose a hundred parts of sugar.

**1057. Vinous Fermentation.**—When the sweet juice of fruits or plants is exposed to the air at the temperature of 70° or 80°, in

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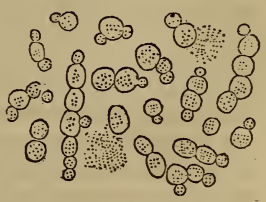
of the latter? Give examples. 1054. What are great natural disinfectants? What of water and heat? 1055. How is fermentation produced? What are ferments? 1056. State their mode of action. When does it cease? What proportion of fer-

the course of a few hours a change commences; small bubbles rise to the surface, the liquid becomes turbid, and begins to ferment, or, as is commonly said, to '*work*.' After a time the bubbles cease to rise and the liquid is no longer sweet, but has acquired a spiritous taste. If now it be distilled, an inflammable body is separated, which is known as *spirits of wine*, or *alcohol*, a product of the decomposition of sugar.

**1058. Yeast.**—During the process of fermentation, a grayish, frothy, bitter liquid is produced, known as *yeast*. When fresh, it is in constant motion, from the escaping gas, but when dried it loses 70 per cent. of its weight, and is converted into a honey-looking solid. Yeast is a minute species of plant. Under the microscope it is seen to consist of numberless small rounded cells. Each little globule consists of an enveloping skin, or membrane of albuminous matter containing a liquid. The yeast cells grow or expand from the minutest microscopic points (*granules*), and also bud off from each other, as shown in Fig. 283. They are never formed except from the decomposition of albuminous substances, and their fermenting power is supposed to be due to the nitrogen they contain. Whatever destroys the vitality of yeast, deprives it of the power of exciting fermentation; hence when it is exposed to a temperature of 212°, its action is destroyed, and it is also checked by a cold of 10°. When yeast is dried and pulverized, or mixed with acids, alcohols, or alkalies, it also loses its power.

FIG. 283.



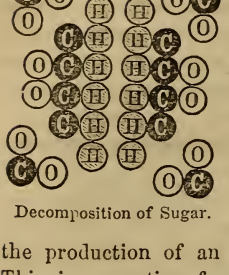
Yeast Plant, showing how it Grows by Budding and by internal Granules.

**1059.** In what manner the yeast plant acts in fermentation is not known. The most probable view is that of PASTEUR, who maintains that the essential condition of fermentation is the conversion of albuminous matter into the membranes of the globules, and the assimilation and decomposition of the sugar in the process of their growth.

**1060. Production of Alcohol.**—When fruit sugar is acted upon by yeast, it is decomposed and gives rise to alcohol and carbonic

ment is necessary? 1057. Describe the vinous fermentation. 1058. What are the conditions of yeast? Of what does it consist? 1059. State PASTEUR'S theory of yeast. 1060. What are the changes when sugars are acted on by yeast? 1061.

Fig. 284.



Decomposition of Sugar.

acid. Two atoms of alcohol and four of carbonic acid are produced, the breaking up into groups being shown by the accompanying figures.

**1061. Diastase.—Malt.**—But the sugar itself may be a product of fermentation. When seeds are exposed to air and moisture at a suitable temperature, germination commences. This consists in a series of changes, of which the first is an alteration of a portion of the nitrogenous matter and the production of an ill-understood compound called *diastase*. This is an active ferment, and taking effect upon the starch changes it to sugar and dextrine. When barley is treated in this way it swells and becomes sweet. Diastase is formed and the barley is termed *malt*. When the germ is about half an inch long the process is arrested by heat, but the dextrine is not destroyed. One part of malt does not contain more than $\frac{1}{100}$ of diastase, but according to Persoz and Payen 1 part of diastase is sufficient to change 2000 of starch. Hence one part of malt can convert the starch of four or five parts of barley into sugar and dextrine.

**1062. Brewing Beer.**—In this process the crushed or ground malt is digested in water at 100° (*malted*), to extract all the soluble matter it contains. The liquid, which is termed *sweet wort*, is then boiled to coagulate the excess of vegetable albumen. Hops are added to impart aroma and a bitter flavor; the cooled wort is then run into a fermenting vat, and yeast is added. In a few hours bubbles of gas begin to rise and the liquid becomes covered with a foam of yeast, which gradually hardens into a crust. This is called *surface yeast*—another portion falls to the bottom and is known as *sediment yeast*. The former requires a higher temperature, and is apt to give rise to lactic acid and other acidulous products. The globules of surface yeast are propagated chiefly by budding. Sediment yeast acts more slowly and at a lower temperature, generates no acid products, and propagates by granules.

**1063.** Though a portion of the yeast is spent in fermentation,

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What is the first change in germination? What is the effect of diastase? Describe malt. What is the effect of heat? Give the proportion of diastase. 1062. Describe the process of brewing beer. How does *surface* differ from *sediment* yeast? 1063. How is the process continued? Name the constituents of beer. 1064. What

a much larger quantity is formed from the nitrogenous matter of the grain in solution. The fermentation is continued several days, but is checked before all the sugar is converted into alcohol, as it would soon turn sour if the decomposition were complete. The liquid is now drawn off into casks, where it undergoes a second protracted fermentation (*ripening*), after which it is kept tightly closed from the air. It contains, in addition to the alcohol, a portion of saccharine, nitrogenous, and aromatic substances, together with various oils and mineral salts.

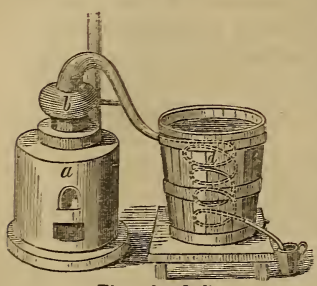
**1064. Lager Beer** is freed from all nitrogenized products by a slow and long-continued fermentation; hence it may be preserved for years without further decomposition. Before consumption it lies stored in vaults for months, from which circumstance its name is derived (*lagen*, to lay). The difference in color of malt liquors is owing to the various degrees of heat employed in malting. *Ale* is made from pale malt, while that used for *porter* is partially charred, giving it a brownish color and bitter flavor.

**1065. Wines** are obtained from the expressed juice of the grape and other fruits. The fresh grape juice, or *must*, is placed in vats in cellars, where the temperature is so low that the fermentation proceeds very slowly. Sometimes the wines are bottled before the fermentation is quite complete, and they continue to generate carbonic acid, which remains compressed within the liquid. If the carbonic acid is so abundant as to produce effervescence when uncorked, the wine is said to be '*sparkling;*' if otherwise, it is termed '*still*' wine. The sweetness of wines is due to undecomposed grape sugar, the ferment being exhausted before all the sugar is changed. This excess of sugar preserves the wine from further decomposition, so that some of the sweet wines, such as Tokay and Muscadine, have been kept uninjured for a couple of centuries. When the sugar is wholly decomposed the wines are called '*dry*,' as Claret, Burgundy, Port, Sherry, &c. The acidity of wines is chiefly due to tartaric acid. Their flavor and aromatic qualities are owing to a volatile substance called *œnanthic ether*, which is developed during fermentation, and also to various other fragrant principles contained in the juice of the grape. Wines contain, in addition to the ingredients named, a proportion of

is lager beer? What causes the difference of color in malt liquors? Examples. 1065. How are wines made? How do sparkling wines differ from still wines? What is the effect of undecomposed sugar? To what is the acidity of wines

various albuminous, oily, and coloring matters, and a small amount of acetic and other vegetable acids.

Fig. 283.




Plan of a Still.

**1066. Distilled** liquors are obtained by subjecting various fermented mixtures to distillation. The plan of a *still* is represented in Fig. 283; *a* is a furnace, *b* a retort, containing the liquid to be separated; and *d* the condenser of cold water surrounding the *worm*, through which the condensed liquid passes. When the fermented mixture is heated above the boiling point of alcohol, 173°, that liquid rises with a portion of the water, passes over, and is condensed. It is then called *spirits of wine*, and when redistilled, *rectified* spirits of wine. The strongest commercial alcohol still contains some 10 per cent. of water, which can only be separated by adding chloride of calcium, or some other substance which has a powerful affinity for water. When the water is entirely removed the alcohol is said to be *absolute* or *anhydrous*.

**1067. Brandy** is derived from the distillation of wine; *rum* from that of fermented molasses, and *arrack* from the distillation of fermented milk. *Whiskey* is obtained from corn, rye, and potatoes, by first converting their starch into sugar, then into spirit, and distilling the product. *Gin* is produced from the distillation of the spirit of a mixture of barley and rye, and owes its peculiar flavor to juniper berries.

**1068. Viscous Fermentation.**—When certain saccharine juices, such as those of beets, carrots, or onions, are exposed to the air at a temperature from 86° to 104°, fermentation takes place, and the sugar disappears, but instead of carbonic acid and alcohol, *lactic acid*, *mannite*, and a mucilaginous, gummy substance are formed, which render the liquid viscid and ropy; it is hence called the *viscous* or lactic acid fermentation. *Mannite* is a substance of a weak saccharine taste, and is not changed to alcohol by fermenta-

owing? Their flavor, &c? Mention other ingredients of wines? 1066 Describe Fig. 283. What is spirits of wine? Rectified spirits of wine? Absolute alcohol? 1067. What is brandy? Rum? Arrack? Whiskey? Gin? 1068. Describe the viscous

tion. It is the chief ingredient of *manna*, a kind of sugar which exudes from a species of ash tree in Southern Europe, and is used as a medicine.

**1069. Lactic Acid,** $C_6H_5O_5,HO$, so called because it occurs in sour milk, is a colorless, sirupy, very acid liquid, which combines with bases, forming a class of salts, the *lactates*.

## § IV. *Alcohol and its Derivatives.*

### ALCOHOL.

**1070. Spirits of Wine**—*Ethylic Alcohol*, $C_4H_6O_2$, *sp. gr. of liquid at* 32° 0.815*: of vapor* 1.613.—Alcohol is a colorless, mobile fluid, having a pleasant, fruity smell, and a burning taste. It is very volatile, about one fifth lighter than water, and has a strong attraction for that liquid, which causes it to absorb moisture from the air, thus rendering it valuable as an antiseptic. It is highly combustible, producing intense heat without smoke, and is therefore well adapted to burn in lamps for chemical use.

**1071.** Alcohol has great value as a solvent, as it acts upon many substances which water does not dissolve, and is easily separated from them on account of its extreme volatility. It boils at 173°, and has never been frozen, although at —166° it becomes viscid. In a concentrated form it is a potent poison, but when sufficiently diluted, it acts upon the animal system as a stimulant. Taken freely in this form it produces inebriation, and is the active principle of all intoxicating liquors. Alcohol, till of late, has been regarded as procurable only by organic decomposition—the destruction of sugar—but it is now made artificially by the synthesis of its elements.

**1072. Derivation of Acetic Acid.**—If the vinous fermentation is not checked at the proper time, it passes on to a second stage, the *acetous fermentation;* the liquid loses its spirit and quality, and becomes *sour*. Oxygen is absorbed, and the alcohol converted into vinegar or *acetic acid*, $C_4H_3O_3,HO$. Pure diluted alcohol does not absorb oxygen when exposed to the atmosphere; it is affected only by adding some matter in a state of change, or which

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fermentation. What are mannite and manna sugar? 1069. What is lactic acid? 1070. Give the composition of alcohol. Its properties. 1071. State some other properties of alcohol. 1072. What is the acetous fermentation? Give the com-

absorbs oxygen. The action proceeds slowly at first, but by degrees a peculiar body, a kind of slimy vegetable mould, is formed, which is known as *mother of vinegar*, and which acts something like a ferment to hasten the process.

**1073. Aldehyd.**—The change from alcohol to acetic acid is not direct—an intermediate substance is formed, called *aldehyd* $C_4H_4O_2$, so named from *al*-cohol *dehy*-drogenated, or deprived of hydrogen. This substance may be produced by the gradual oxidation of alcohol, in various ways, or by transmitting a mixture of alcohol and air through a porcelain tube at a low red heat. Aldehyd is a highly volatile, inflammable liquid, with a pungent, apple-like odor.

Fig. 284.

Oxidation of Alcohol.

**1074.** When a few drops of alcohol are placed in a cup, its vapor will mingle with the air. If now a red hot coil of platinum wire be introduced into the cup, Fig. 284, the oxidation of the vapor commences (471), pungent odors of aldehyd are given off, and the wire is kept at a red heat by the continued oxidation. If the coil be suspended over the wick of an alcohol or ether lamp, Fig. 285, it will continue to glow for hours after the flame is extinguished, from the same cause.

Fig. 285.

Flameless Lamp.

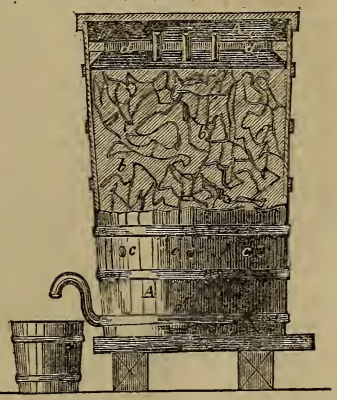
**1075. The Quick Vinegar Process.**—As oxygen is the active agent in acetification, the rapidity of the process will obviously depend upon the abundance of its supply. If the air comes in contact with but a small portion of the liquid, months may be required to produce the change. In the quick vinegar process the liquid is made to trickle over beech shavings, which have been previously soaked in vinegar, and placed in a tall vessel. In Fig. 286 A A represents such a tub, near the top of which is a perforated shelf *d d*, through which the liquid falls. The shavings, loosely packed at *b*, rest upon a perforated shelf just above *c c c*, which are apertures for admission of air; the glass tubes in the cover allowing its escape. By this arrangement a vast surface is exposed, the absorption is very rapid, and the acetification is completed by a few

position of vinegar. How is the mother of vinegar formed? 1073. What is aldehyd, and why so named? Its properties? 1074. What is the effect of a hot platinum coil upon alcohol vapor? 1075. Upon what does the rapidity of acetification

repetitions of the process. Any fermented liquid, as a mixture of crude spirits and water, may be used.

**1076. Properties of Acetic Acid.**—Pure acetic acid is a colorless, intensely sour liquid, which has a pungent odor, and blisters the skin. Mixed with various proportions of water it forms vinegar of different degrees of strength; common table vinegar contains from three to four per cent. of acetic acid. *Acetates* are salts of acetic acid, all very soluble. *Verdigris* is an acetate of oxide of copper, which forms a green paint. Acetate of lead (*sugar of lead*) is soluble in pure water, and has a sweet, astringent taste. Acetates of alumina, iron, and ammonia, are used in dyeing and in medicine.

Fig. 286.



The Quick Vinegar Process.

**1077. Ether, $C_4H_5O$** (*Sulphuric Ether*).—When equal weights of oil of vitriol and alcohol are heated in a retort, a vapor passes over which may be condensed into a limpid fluid, called *ether* from its volatility, and sulphuric ether, because in obtaining it sulphuric acid is employed. In composition ether is alcohol less the elements of an atom of water, which is separated by the sulphuric acid.

**1078.** Ether is colorless, with a fragrant odor, and a hot, pungent taste. It is so volatile that it disappears when poured through the air from one vessel to another, and when placed upon the hand, produces cold by rapid evaporation. It boils at 96°, or when exposed to the air in summer, and is very combustible, burning with more light than alcohol and some smoke. Its vapor, when mixed with air, is explosive. It readily dissolves fats and oils.

**1079. Alcohols and Ethers.**—By the chemist the substances

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depend? Describe the quick vinegar process, Fig. 286. 1076. State the properties of acetic acid. What are acetates? Examples. 1077. What is the composition of ether? How is it produced? From what is the term sulphuric ether derived? 1078. What are the properties of ether? 1079. why are the alcohols and ethers in-

we have just been considering have an interest as types of large and important classes of compounds, having analogous properties and relations. The term alcohol was formerly restricted to the vinous product just described, but it has now become generic and embraces a large group of homologous substances (915). All organic compounds of carbon, oxygen, and hydrogen which unite with acids and separate the elements of water, forming ethers, are known as alcohols. There is a class of ethers derived from the alcohols by distilling them with different acids, as nitric ether, butyric ether, carbonic ether, &c.

**1080.** The composition of *Formic Acid* is $C_2H, O_3, HO$ or hydrated teroxide of formyle. It is a clear, pungent, strongly acid liquid, which was first obtained by distilling the bodies of red ants (*formica rubra*) in water, hence its name *formic* acid. It is this acid which causes the painful, stinging sensation, produced by handling the nettle, as its leaves are covered with little, sharp, hollow spines, with elastic cells at the base filled with the liquid.

**1081. Chloroform,** $C_2HCl_3$, is a terchloride of formyle, and is prepared by distilling alcohol with a solution of chloride of lime. It is a colorless, volatile liquid, of a strong, agreeable odor, and a sweet, penetrating taste. It dissolves sparingly in water, but freely in alcohol and ether. It is extensively employed in medicine, but for this purpose it should be perfectly pure, as the fatal effects which have sometimes attended its use are doubtless chiefly owing to its contaminations. It should be colorless and free from a chlorous smell, or any unpleasant odor, when a few drops are evaporated on the hand.

**1082. Anæsthetics.**—Chloroform and ether are the most important representatives of a class of bodies, the vapor of which when inhaled produces temporary insensibility to pain, or *anæsthesia*; these substances being known as *anæsthetics*. For a hundred years physicians have sought for agents that would so deaden consciousness, that surgical operations might be performed without inflicting pain; chemical science has at length furnished the inestimable boon.

**1083. Amylic Alcohol.**—In the crude spirit obtained by distil-

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teresting to the chemist? What does the term alcohols include? 1080. How is formic acid obtained, and what are its properties? 1081. What is chloroform, and how prepared? Its properties? What precautions should be observed? 1082. What is said of anæsthetics? 1083. Describe fusel oil. How is it regarded, and

ling grain and potatoes, there is generated a disagreeable, pungent, oily body, known as *fusel oil.* It is regarded as the hydrated oxide of the radicle amyle $C_{10}H_{11}O_9HO$. It has a persistent odor, a burning taste, and, though existing in but small proportion in distilled liquors, it increases their intoxicating effect.

**1084. Artificial Fragrant Ethers.**—By the action of the various acids upon the alcohols, a great number of fragrant ethers are produced. When amylic alcohol is distilled with oil of vitriol and acetate of potash and mixed with six times its bulk of alcohol, it gives the product known as '*pear oil,*' which has the odor and flavor of the Jargonelle pear. If bichromate of potash is used in place of the acetate, apple oil is produced, and in the same manner other acids produce the flavor of melons, quinces, bananas, oranges, &c., which are much used by confectioners as 'flavoring essences.' The flavoring principles of various flowers, and of spirituous liquors, are also produced in this way, and extensively employed in perfumery and in the manufacture of wines and other liquors from alcohol.

**1085. Mercaptans**—*Sulphur Alcohols.*—The ogygen of the alcohols may be replaced by sulphur, forming *sulphur alcohols,* which have a strong affinity for mercury, and are hence called *mercaptans.* They have a very offensive odor, resembling garlic. The radical Kakodyl, $C_4H_6As$, is a colorless, viscous liquid, emitting fumes which, from their strong affinity for oxygen, take fire spontaneously when exposed to the air. It is highly poisonous and produces an intolerable stench. It is of much chemical interest, as it was the first organic base which played the part of a simple metallic body and could replace hydrogen.

## CHAPTER XXIII.

### ANIMAL PRODUCTS.

### § I. *Animal Structures.*

**1086. Composition of Flesh.**—The muscular parts of animals consist of fibrin, separated into bundles by membranes, and into

what are its properties? 1084. How are artificial fragrant ethers produced? How is pear oil obtained? Apple oil, &c.? What other flavoring principles are thus produced? 1085. What are mercaptans? What of kakodyl? 1086. Of what

larger separate masses by cellular tissues in which fat is deposited. The fleshy mass is penetrated by a network of blood vessels called veins, and the whole is distended by water, which forms about three fourths of the weight of the meat. The composition of the muscular flesh of different animals, according to BRANDE, is as follows:

| | Water. | Albumen and Fibrin. | Gelatin. | Total solid matter. |
|---|---|---|---|---|
| Beef, . . . | 74 | 20 | 6 | 26 |
| Veal, . . . . | 75 | 19 | 6 | 25 |
| Mutton, . . . | 71 | 22 | 7 | 29 |
| Pork, . . . . | 76 | 1. | 5 | 24 |
| Chicken, . . . | 73 | 20 | 7 | 27 |
| Cod, . . . . | 79 | 14 | 7 | 21 |

**1087. Juice of Flesh.**—The true color of flesh fibrin is white, but it is ordinarily stained reddish by the coloring matter of the blood. Yet the liquid of meat is not blood; when that has been withdrawn from the animal, there remains diffused through the muscular mass a peculiar liquid known as the *juice of flesh*. It consists of the water of flesh, containing about 5 per cent. of dissolved substances, one half of which is albumen and the remainder a mixture of several compounds not yet examined. The juice of flesh may be separated by finely mincing the meat, soaking it in water and pressing it. The solid residue is white, tasteless, and inodorous. The separated juice is uniformly and strongly acid, from the presence of lactic and phosphoric acids; hence it is in an opposite state to that of the blood, which is invariably alkaline.

**1088. Creatin.**—The juice of flesh contains the savory principles which give flavor to meat, and which cause it to differ in different animals. It also contains two nitrogenous crystallizable compounds, called *creatin* and *creatinin*. Creatin ($C_3H_9N_3O_4 + 2$ Aq.) is a neutral substance, while *creatinin* ($C_3H_7N_3O_2$) is a powerful organic base of a similar nature with theine and caffeine. *Inosic acid* is a sirupy liquid derived from meat, and has an agreeable taste of the juice of flesh. *Inosin* or muscle sugar is found in the juice of flesh, the heart yielding it most readily. It has a sweet taste, is soluble in water, and forms crystals.

**1089. Gelatin.**—When the tendons, ligaments, cartilages, skin,

does the muscular part of animals consist? What of the fleshy mass? 1087. What gives color to flesh fibrin? Is the juice of meat blood? What is the juice of flesh? How may it be separated, and what is the residue? Mention the difference between the juice of flesh and blood? 1088. What does the juice of flesh contain. What of creatin and creatinin? Describe inosic acid. Inosin. 1089. How is gel-

and bones of animals are for some time boiled in water, a substance is extracted which, on being cooled, hardens to a jelly. This is called *gelatin*. It is a nitrogenized compound, with the formula $C_{13}H_{10}N_2O_5S$; but, unlike the albuminous substances, it is never found in plants, nor is it a constituent of the blood. Some chemists maintain that it is formed by the process employed to obtain it, and has no real existence in the animal organism. Pure gelatin is colorless, transparent, inodorous and insipid. In cold water it gradually softens and swells, but does not dissolve till heated. It is insoluble in alcohol, ether, and the fixed and volatile oils.

**1090. Isinglass** is the purest form of commercial gelatin, and is obtained chiefly from the air bladders of fish, as the sturgeon and cod. It is extensively employed as an article of diet in the form of jelly. The gelatin from cartilage is termed *chondrin*, and differs somewhat from ordinary gelatin.

**1091. Dietetical Value of Gelatin.**—Gelatin, in the form of calves-foot jelly, blanc-mange, &c., is much used as an article of food, and it is also the chief thickening element of soups produced by long boiling of animal substances. Though a nitrogenous body, it is not of the protein type. It is regarded as a product of the partial decomposition of albuminous bodies in the system, but as incapable of replacing them when taken as aliment. The French attempted to feed the inmates of their hospitals on gelatinous extract of bones. Murmurs arose, and a commission, with MAGENDIE at its head, was appointed to investigate the matter. They reported gelatin as, dietetically, almost worthless; but it is probably of some value, especially to invalids, as a diluent of nutritious food.

**1092. Glue** is a form of gelatin extracted from bones, and the refuse skin, hoofs, and ears of cattle, by boiling them in water, and evaporating the solution. Good glue is hard, brittle, translucent, of a brownish color, and absorbs three or four times its weight of water without dissolving. *Size* is an undried or gelatinous glue, made from the parings of parchment—the thinner kinds of skins. When applied to paper, it fills up its pores, and thus prevents the spreading of ink.

atin obtained? What is further said of it? State its properties. 1090. What of isinglass? Chondrin? 1091. What is said of the dietetical value of gelatin? What of the French investigation? 1092. What is glue? Its properties? What

**1093. Leather.**—Gelatin combines with tannic acid, forming the basis of leather. The skins, first softened by soaking, are placed in vats containing lime water, which dissolves the sheaths of the hairs, and permits their ready removal. When freed from hair, and soaked in a weak solution of acid, to neutralize the lime, they are transferred to tan pits. These contain a weak solution of bark, the tannic acid of which slowly penetrates the skin, and, uniting with the gelatin, forms the leathery compound. The operation is slow, requiring many months, as no quickening process yet contrived produces so excellent an article. *Currying* consists in impregnating the skin with oil, and working it into a pliable state.

**1094. Bones.**—Bones consist of gelatinous tissue, into which mineral matter has been deposited until it possesses a stony hardness. The mineral substances are chiefly phosphate and carbonate of lime. The phosphate predominates in the higher animals; in the lower, the carbonate. The amount of mineral substances in bones increases with age; in the adult man, it forms about two thirds of the weight of the bone.

**1095.** If a bone is soaked in diluted chlorohydric acid, the mineral salts are dissolved out; the organic matter remaining as tough, flexible, nearly transparent gelatin, having the same form as the bone. But if we submit a bone to strong heat, the animal portion is burned out, and the earthy part remains. The bone is then brittle and falls to pieces at the slightest touch. Hence, bony structures owe their tenacity to the organic element, and their hardness and stiffness to the mineral substances of which they consist. The bones of fish contain a large proportion of organic matter, which accounts for their flexibility.

**1096. The Teeth** are similar in composition to the bones, but contain less organic matter. The enamel of the teeth contains, in addition to phosphate and carbonate of lime, a proportion of fluoride of calcium.

**1097. Horny matter,** which forms the hair, wool, feathers, claws, nails, and hoofs of animals, has about the same ultimate

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is size, and for what used? 1093. How is leather prepared? What is currying? 1094. Of what do bones consist? What of their mineral constituents? 1095. What results if a bone be steeped in dilute chlorohydric acid? If exposed to strong heat? To what do they owe their different properties? What of the bones of fish? 1096. Of the teeth? 1097. What of horny matter? To what is the color of

composition as gelatin, but resembles more closely the albuminous bodies in its reactions. It contains but a small proportion of saline matter, is insoluble in water, and is dissolved with difficulty by caustic alkalies. The substances composed of it owe their peculiar colors to the animal oils which they contain. The skin is closely allied to horny matter in its composition.

**1098. Shells.**—The shells of the mollusca, oysters, clams, &c., and of the eggs of birds are composed almost wholly of carbonate of lime; while those of the crustacea, as lobsters, crabs, &c., generally consist of only half their weight of carbonate of lime, the remainder being animal matter with a small proportion of phosphate.

## § II. *Animal Secretions.*

**1099.** *Animal Secretions* are the liquids separated from the blood and poured out by various organs of the living body for special purposes; as tears to moisten the eyes, gastric juice for solution of food, &c.

**1100. Milk.**—This familiar liquid is secreted from the blood of the females of the class mammalia for the nourishment of their young. It is the only substance prepared by nature as an article of food, which furnishes all the materials for the development of the various organs and compounds of the young animal. Its composition is, therefore, a matter of much physiological interest. An analysis of fresh cow's milk gave

| | |
|---|---|
| Water, | 88.30 |
| Casein, | 4.82 |
| Milk Sugar, | 3.39 |
| Butter, | 3.00 |
| Salts, | 0.49 |
| Solid Matter, | 100.00 |
| | 11.70 |

The five great types of food are thus represented, viz.: 1st, the aqueous; 2d, the albuminous; 3d, the saccharine; 4th, the oleaginous; 5th, the saline.

**1101. The Oily Element.**—In respect to its sugar, casein, and salts, milk is a *solution*, but with reference to its oily part it is an

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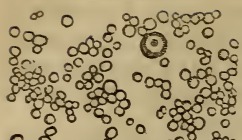
hair, feathers, &c., due? 1098. Give the composition of shells. 1099. What are animal secretions? 1100. What is said of milk as food? What are its constituents? What does it represent? 1101. How does milk appear as seen by the mi-

Fig. 287.



Milk Globules.

*emulsion*. The butter of milk is diffused through it in the form of exceedingly minute globules, which when viewed by the microscope appear floating in a transparent liquid, Fig. 287. The milk globules are lighter than water, and hence, when the milk is allowed to stand undisturbed, they slowly rise to the surface, forming cream. Each little globule is invested by a thin membrane of casein, which is ruptured by the agitation of churning, causing the butter to cohere in a separated mass.

**1102. Spontaneous Curdling.**—When milk is allowed to stand for a short time it sours and curdles; that is, its casein changes from the dissolved to the solid state. This is brought about by a series of interesting changes, originating in the unceasing activity of atmospheric oxygen. Casein is insoluble in water. But in the milk it exists combined with soda, and this compound dissolves in water. Now when fresh milk is exposed to the air its oxygen seizes upon a portion of the casein and changes it to a ferment; this takes effect upon the milk sugar and converts it into lactic acid, which causes the sourness of the milk. When a sufficient quantity of the lactic acid is thus formed, it seizes upon the soda, takes it away from the casein, and forms *lactate of soda*. The casein, thus set free, shrinks in bulk and gathers into an insoluble, curdy mass.

**1103. Artificial Curdling.**—In making cheese the milk is curdled artificially, and in different countries various substances are employed for this purpose. Almost any acid will curdle milk, and vinegar, lemon juice, dilute muriatic acid, &c., are used to produce this effect. But the substance most generally employed for this purpose is *rennet*—the lining membrane of the stomach of a calf, salted and dried. The rennet is soaked in water, or whey, which, being added to milk at a temperature of 95°, coagulates it promptly. It was formerly supposed that the action of the gastric juice of the rennet produced the change, but the membrane acts with equal promptitude when washed thoroughly free from all

croscope? How is cream formed? Butter? 1102. What is the cause of the curdling of milk? Explain the chemical changes. 1103. State the effect of acids upon milk. What is generally used to curdle milk? To what is the change

acid. The change is due to the decomposing animal matter of the rennet. This converts milk sugar to lactic acid, which neutralizes the soda, and precipitates the casein. Only a minute quantity of rennet is necessary; according to BERZELIUS, one part of the membrane being sufficient to coagulate thirty-thousand parts of milk.

**1104. Cheese.**—By the act of curdling, the milk is divided into two parts: first, the *curd*, comprising all the casein, a large portion of oil, and a trace of sugar of milk, with some water; and second, the *whey*, or fluid part, containing the bulk of water, the sugar of milk, and a small, variable proportion of oily matter. Of the saline matter in milk, the phosphates of lime and magnesia exist in the curd, while the remaining salts are found in the whey. The curd, separated from the whey and prepared in various ways, forms, when pressed, *cheese*.

**1105. Renal Secretion (*Urine*).**—This liquid is separated from the arterial blood by the kidneys, and contains the chief soluble waste products of the body. In fasting it is feebly acid, but during digestion it becomes slightly alkaline. When left undisturbed for a time (which varies with the temperature), it putrefies, acquires a powerful alkaline reaction, and gives off ammonia. This excretion is the outlet of the nitrogenous products of the decomposed tissues, and of the saline constituents of the body.

**1106. Urea,** $C_2H_4N_2O_2$, is the chief product of the kidney excretion. It is a neutral body, crystallizes in slender prisms, and forms compounds with salts. It is not formed in the kidneys, but is separated by them from the blood. *Uric*, or *lithic acid*, $C_{10}H_4N_4O_6$, is a small constituent of human urine, but abounds in the excretion of birds and serpents. Urate of ammonia is the chief constituent of guano. It is this acid, principally, in combination with soda, which accumulates around the joints in gout, and it is also a constituent of several of the stony concretions known as *urinary calculi*. *Hippuric acid* is another nitrogenous body found in urine.

**1107.** The openings from the surface of the body are lined with what are known as *mucous membranes*, which are constantly

owing? What proportion of rennet is necessary? 1104. Into what does curdling divide the milk? Give the constituents of the curd. Of the whey. What is cheese? 1105. What is the origin of urine? State its different conditions. Of what is it the outlet? 1106. What of urea? Where is uric acid found? What is said of it in con-

moistened by a viscid secretion called *mucus*. This is insoluble in water, and yields a glairy product called *mucin*.

# CHAPTER XXIV.

## CHEMISTRY OF FOOD.

### § I. *Chemistry of Bread Making.*

**1108. Objects of Culinary Art.**—Organized substances designed as human food—grains, roots, fruit and flesh—are many of them not adapted for this purpose in their natural condition, and to become digestible, require to be mechanically and chemically changed. This is effected chiefly by water and heat. These agencies soften some substances, dissolve others, and enable us to prepare palatable and nutritious dishes from the crude, tasteless, or noxious bodies furnished us by Nature.

**1109. Preparing the Dough for Bread.**—This is usually done by first mixing suitable proportions of flour, water, yeast, and salt into a stiff batter, and exposing it for an hour or two to a gentle heat. The water hydrates the starch, dissolves the sugar and albumen, and moistens the dry particles of the gluten, causing them to cement together all the ingredients into a cohering mass. The yeast now causes an active fermentation, converting the sugar of the flour into alcohol and carbonic acid. It also converts a portion of the starch into sugar. The carbonic acid is diffused throughout the mass in the form of minute bubbles, which, being caught by the tenacious gluten, cause the dough to swell and rise. When the fermentation is sufficient, the dough is kneaded into loaves for the oven. Leavened bread is made by substituting for yeast a ferment of sour flour paste (*leaven*).

**1110. Changes of Bread in Baking.**—When the prepared dough is exposed in an oven to a temperature of 350°, it loses from 10 to 16 per cent. of its weight by evaporation. But the

nection with gout and urinary calculi? 1107. What of mucus? 1108. What changes must many organized bodies undergo to fit them for food? How are they effected? 1109. How is bread dough prepared? What changes does the yeast produce? Why does the bread rise? What is leavened bread? 1110. How does heat affect

loaf increases in bulk to about twice its size. This is due to the expansion of the carbonic acid contained in its pores, the conversion of water into steam, and the vaporizing of alcohol, which is driven off in the gaseous form. Attempts have been made in large bakeries to condense and save the alcohol, and a weak spirit was obtained, but it seems not to have repaid the trouble of its collection. The surface of the loaf is first dried and then disorganized. The roasting converts the starch into gum, and produces a peculiar, brown, soluble substance, known as *assamar*. If the heat is excessive, a thick carbonaceous crust is formed, which prevents the penetration of heat, and produces a raw interior.

**1111.** As the temperature within the loaf cannot rise above 212°, no changes go on there except such as are produced by the heat of the watery vapor. This is sufficient to stop the fermentation, destroy the bitter principle of the yeast, and kill the yeast plant. In baking, about $\frac{1}{14}$ of the starch is converted into gum, the rest remaining chemically unchanged. The gluten, though not decomposed, loses its tough qualities, and unites closely with the starch paste.

**1112. New and Stale Bread.**—In newly baked bread the crust is dry and crisp, while the crumb is soft and moist, but after a short time this condition of things is quite reversed; the brown products of the roasting process attract moisture, and the crust grows daily softer, while the crumb becomes hard and dry. This apparent dryness, however, is not caused by loss of water, but by combinations going on among the watery and solid atoms of the bread. That the moisture has only passed into a state of concealment may be shown by exposing a stale loaf in a closely covered tin vessel for half an hour to a heat of 130°, when it will again have the appearance of new bread. Well-baked wheaten bread contains on an average about 45 per cent. of water, so that the bread we eat is nearly one half water.

**1113. Aerated Bread.**—A new method has lately come into use in which carbonic acid is forced, under high pressure, into the water

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the bread? To what is its increase in bulk owing? What attempts are mentioned? Describe the changes of the crust. 1111. To what are the changes within the loaf due? In what do they consist? 1112. What differences are mentioned between the crust and crumb? To what is the dryness of the latter owing? How is it proved? What proportion of water does bread contain? 1113. How is aërated bread made?

employed for making the dough. The intermixture of the materials, or *kneading*, is effected by machinery under great pressure. As soon as the pressure is removed, the dough, rises from the expansion of the compressed carbonic acid.

**1114. Use of Chemical Substances.**—Fermentation is often replaced by a quicker method of raising the dough, through the agency of chemicals. Bicarbonate of soda and chlorohydric acid are used, the soda being thoroughly incorporated with the flour, and the acid added to the water used for mixing. The acid combines with the alkali, forming common salt, and carbonic acid is set free, which distends the dough. To ensure neutralization, the ingredients should be pure, the proportions correct, and the mixture perfect. *Soda powders* consist of tartaric acid and bicarbonate of soda. The soda combines with the acid, producing tartrate of soda, and liberating carbonic acid. Cream of tartar is extensively employed. When sour milk is used, the carbonic acid is set free by lactic acid.

**1115. Phosphated Bread.**—The high price and pernicious adulteration of cream of tartar have created a demand for a substitute. Prof. HORSFORD claims to have found it in phosphoric acid, or acid phosphate of lime, which combines with the soda, setting free carbonic acid, and producing phosphate of soda and lime; both normal constituents of the body. This preparation is now furnished as a yeast powder.

**1116. Salts of Ammonia** are sometimes employed for raising dough, but the gases formed are apt to communicate a disagreeable hartshorn flavor to the bread. All these chemical methods have one serious disadvantage—the gas is set free too suddenly to produce the best effect. The cautious use of chemicals, when pure, in bread making may be tolerated on grounds of convenience, but their employment by careless housekeepers in the commercial form is highly injudicious, as they are apt to be contaminated with injurious, and even poisonous impurities.

**1117. Deterioration of Flour.**—Flour tends to deteriorate by time. It is very hygroscopic, and the absorbed water gradually

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1114. By what is fermentation often replaced? What chemicals are mentioned? Explain their action? What precautions are necessary? What of soda powders? Sour milk? 1115. What is Prof. HORSFORD'S substitute for cream of tartar? Describe its action. 1116. What of salts of ammonia? State the disadvantage of all these chemicals. What is said of the use of chemicals? 1117. Why does flour

impairs the tenacity and fineness of the gluten. Oddling has shown that it is converted into a substance resembling diastase, which changes the starch of the flour into dextrine and sugar. Such flour of course makes a heavy, sodden bread; flour, therefore, should be preserved in a state of the utmost dryness. Liebig has ascertained that flour thus damaged may be greatly improved by lime water; 100 parts of flour are mixed with 26 or 27 of lime water, and sufficient water added to form dough. The lime removes all acidity from the dough, somewhat augments the proportion of water absorbed, and restores the original qualities of the gluten. Common salt and alum cause dough to absorb more water than it would otherwise do.

## § II. *Culinary Changes of Alimentary Substances.*

**1118. Effects of Boiling.**—In boiling the food is surrounded by a powerful solvent, which more or less completely extracts certain constituents of the food. Vegetable acids, sugar, gum, and vegetable albumen are all soluble in water, and by boiling are partially removed. The tougher parts are made tender, the hard parts softened, and the connections of the fibres and tissues loosened, so as to be more readily masticated, more easily penetrated by the saliva and juices of the stomach, and therefore more promptly and perfectly digested.

Fig. 288.

Starch Grain Fractured.

**1119. Breaking up of the Starch Grains.**—The structure of starch grains has been described. They consist of layers or coats arranged concentrically around a point called the *hilum*. If one of these grains be strongly compressed between two plates of glass it breaks apart into several pieces, as seen in Fig. 288; but under the joint action of heat and water the membranes are torn asunder, or exfoliated, by internal swelling, as represented by Fig. 289.

Fig. 289.

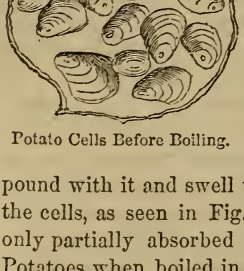
Starch Grains Ruptured by Boiling.

deteriorate? What has Oddling shown? How should flour be kept? What is Liebig's remedy? What change does the lime effect? 1118. How does boiling change food? 1119. What is the structure of starch grains? What do figures

**1120. Changes of Starch.**—When starch is diluted with twelve or fifteen times its weight of water, and slowly heated, all the grains burst on approaching the boiling point, and swell to such a degree as to occupy nearly the whole volume of the liquid, forming a gelatinous paste. If a little of this be diffused through cold water, and examined with the microscope, it will be seen that the starch grains have greatly changed. They have increased to twenty or thirty times their original size; the concentric lines are obliterated; the membrane of the grain is ruptured, and its interior matter has escaped. When starch is boiled in water for a considerable time it gradually changes, first into gum and then into sugar. A cold starch jelly left to stand, either closed or exposed to the air, undergoes the same change, but to effect it, months are required.

**1121. How Potatoes are Changed by Cooking.**—The potato is composed of three fourths water, and one fourth solid matter, which consists chiefly of starch. When examined by the microscope the tissue is found to consist of a mass of cells, each inclosing some 10 or 12 starch grains, loosely situated, as shown in Fig. 290, and surrounded by the potato juice, which contains albumen. If potatoes be of good quality they boil dry, or *mealy*, as it is termed; but their juice does not separate or boil out. It is absorbed by the starch grains, which form a compound with it and swell up, so as completely to fill and even burst the cells, as seen in Fig. 291. When the juice of the potatoes is only partially absorbed by the starch they are *watery* or *waxy*. Potatoes when boiled in water do not form a jelly, like common starch, because the starch grains are protected, partly by the coats of the cells in which they are inclosed, and partly by the coagulated albumen.

FIG. 290.



Potato Cells Before Boiling.

**1122. Quality of Water for Culinary Purposes.**—Soft water,

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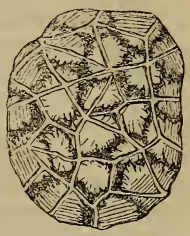
illustrate? 1120. How is a solution of starch affected by heat? What changes are seen with the microscope? When starch is boiled for some time, what changes occur? What is the effect of exposing starch jelly to the air? 1121. Of what is the potato composed? What does Fig. 290 illustrate? What becomes of the juice when potatoes boil *mealy*? When are they *watery*? Why do not potatoes form

or that which is free from dissolved mineral matter, makes its way into organized tissues with much more readiness than hard water. Its higher solvent power better fits it also to act as a vehicle for conveying food into the living system. In culinary operations, where the object is to soften the texture of animal and vegetable matter, or to extract from it and present in a liquid form some of its valuable parts, as in making soups, broths, or infusions (as of tea and coffee), soft water is the best. But there are cases in which the solvent action of soft water is too great, as sometimes upon green vegetables, which it makes over tender, destroying the firmness that is essential to the preservation of their juices, which are dissolved and extracted, rendering the substance proportionately tasteless. In those cases therefore, where we do not desire to dissolve out the contents of a structure, but to preserve it firm and entire, hard water is better than soft. To prevent this over-dissolving action, soft water is often hardened by the addition of common salt, which also hinders the evaporation of the flavoring principles.

Fig. 291.



After Boiling.

**1123. Constituents of Flesh.**—When lean meat is chopped fine and soaked in cold water, there remains a solid residue consisting of the fibres, tissues, &c. It is white, tasteless, and inodorous. All the savory constituents of the flesh were contained in its juice, and were entirely removed by cold water. If the watery infusion thus produced be boiled, a clear, yellowish liquid is obtained which has the aromatic taste and other properties of soup made by boiling the flesh. When evaporated and dried, a soft, brown mass, amounting to 12 or 15 per cent. of the weight of the original dry flesh, is left, having an intense flavor of roast meat. This extract, when dissolved in hot water, gives to it all the properties of soup, retaining the peculiar taste of the flesh from which it was derived.

**1124. Action of Heat upon the Constituents of Flesh.**—The

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a jelly? 1122. What is said of soft water as a solvent? When should it be used? When is its solvent power too great? When is hard water to be preferred in cooking? What effect has the addition of salt? 1123. What is the result when lean meat is chopped fine and soaked in cold water? State the effect of boiling this liquid infusion? What of this product when dried and evaporated? 1124. Describe

effect of boiling upon fibrin is to render it hard and tough. Heat, as we have seen, changes liquid albumen to the solid condition, and renders it insoluble in water, either hot or cold. Fat is, of course, liquefied by the action of heat and, at a high temperature, is resolved into various acid and acrid bodies.

**1125. The Cooking of Meat.**—The first effect of applying a strong heat to fresh meat is to contract its fibres, press out a portion of the juice, and prevent the escape of more by partially closing the pores. In preparing meat for food, it is desirable that it should retain the ingredients of its juice; and this will depend much upon the method of culinary procedure. If the meat be introduced into the water *when briskly boiling*, the albumen at its surface, and to a certain depth inward, is immediately coagulated; thus enclosing the mass in a crust which prevents the juice from escaping, and also from being weakened and dissolved by the external water penetrating within. The albumen coagulated within the meat also forms a protective sheath around the fibres, and thus prevents them from becoming shrivelled, tough, and hard by boiling. If, on the contrary, the meat be placed in cold water, and the temperature slowly raised to boiling, a portion of the savory and nutritive juices is dissolved out, and the meat becomes proportionally poorer for the loss, while, at the same time, the fibres grow hard and tough. Whether the meat be surrounded by hot water, or exposed to heat in any other way, as soon as the water-proof coating is formed, the further changes are effected by internal vapor, or steam. In *roasting* or *baking*, therefore, the fire should at first be quite hot, as meat, when exposed to a slow heat, becomes dry and unsavory, from the constant escape of its juices through the open pores.

**1126. Soups.**—In the preparation of these, our object is the reverse of that just considered. We desire to take the nutritive and savory principles *out* of the meat, and obtain them in a liquid, or soluble form. To obtain the best liquid extract of meat in the form of soup, broth, or tea, the flesh is finely chopped and placed

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the action of heat upon the constituents of flesh. 1125. Mention its first effect. What is desirable in cooking meat? How does boiling water act upon meat? What is the result of placing meat in cold water and slowly raising its temperature? After the water-proof coating is formed, how are the further changes produced? Why, in roasting or baking meat, should the fire be at first quite hot? 1126. What is the object in preparing soups? How is this best effected? Why is

in *cold water*, which is then slowly heated and kept boiling for a few minutes, when it is strained and pressed. The meat should not be boiled long, as the effect is to coagulate and render insoluble the ingredients extracted by the cold water, and which should have remained *dissolved* in the soup.

**1127. The Effect of Salt,** when rubbed upon raw fresh meat, is to contract its fibres, thereby pressing out the juices, so that a brine is soon formed without the addition of any other liquid. This brine contains a large proportion of the albuminous constituents and mineral salts of the meat, the removal of which impoverishes it and renders it incapable of complete or healthful nutrition. Salted meat is, therefore, dietetically much inferior to fresh meat.

## CHAPTER XXV.

### CHEMISTRY OF SOILS.

**1128.** A few years since a remarkable impulse was given to the subject of Agricultural Chemistry, chiefly through the labors of Prof. LIEBIG. The first effect of the movement was to create extravagant expectations in regard to what chemistry could accomplish for agriculture. It was supposed that the farmer had only to obtain an analysis of his soil, and by comparing the results with tables of the composition of crops, he could, by supplying the missing constituents, place his agriculture at once upon a simple, scientific, and successful basis. Experience quickly dissipated this fallacy, and then came a reaction, in which agricultural chemistry was denounced as misleading and worthless. The truth in this case lies between the extremes. While chemistry cannot be made a sole guide in agriculture, it can contribute important assistance, and is indispensable to the enlightened and most successful practice of the art.

**1129.** Prof. ANDERSON states that it is only in rare instances possible to connect together the chemical composition and properties of the soil; that analysis is frequently incapable of dis-

long boiling injurious? 1127. How does salt affect raw meat? Why are salted meats less nutritious than fresh? 1128. what is said of LIEBIG? What was the first effect of this impulse? Its reaction? Where does the truth lie? 1129. Give

tinguishing between a fertile and a barren soil; that it discloses only a *part* of the conditions of fertility, and that with each advancement in the accuracy of its processes the difficulties have increased, rather than diminished. Still, in the study of soils we cannot dispense with the aid that chemistry affords.

**1130. Origin of Soils.**—The mineral elements which compose the chief mass of soils are derived from the disintegration of rocks by air and moisture, heat and frost. Of course the composition of the rock determines that of the soil derived from it—an argillaceous rock producing a soil abounding in clay; a calcareous rock in lime; a silicious rock in sand. There is hence a relation between soils and the rocks from which they are derived, but it is made so obscure by the transportation and admixture of materials, as to be discoverable only by the well-instructed geologist.

**1131.** In the crumbling down of rocks into soil, the decomposition is not complete. Besides a portion of liberated alkalies and alkaline earths, the sands and clays contain large amounts of potash, soda lime, and magnesia, locked up in combination, so as to be imperfectly or not at all available to growing vegetation. Yet the same forces, which disintegrated the rocks are still at work upon these constituents of soils, carrying forward the same decomposing changes, and gradually liberating the needed elements of fertility.

**1132. Variety of Soils.**—Soils are named from their predominating element, as *sandy*, *argillaceous*, *calcareous*. Those containing excess of sand are light and porous; water escapes through them; manures are wasted, and in drought plants languish and die. On the other hand, an excess of clay makes a soil stiff, heavy, and retentive. A due admixture forms the *loamy* soil in which the evils of both extremes are corrected. It is sufficiently open to permit the free extension of the roots, and the admission of air, while moisture and manures are retained.

**1133. Physical Properties of Soils.**—The most important of these are specific gravity, tenacity, power of retaining moisture, of absorbing and retaining heat, and of absorbing moisture, carbonic acid, ammonia, and oxgyen from the air. These properties are most powerfully influenced by drainage, deep and subsoil plough-

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Prof. ANDERSON'S testimony. 1130 How do soils originate? What is said of their composition? 1131. What do the sands and clays contain? How are they fertilized? 1132. Describe the varieties of soil. 1133. Mention their physical

ing, mixture of soils, &c. But it is impossible to alter the physical character of soils without at the same time affecting their chemical properties.

**1134. Chemical Properties.**—These relate to the composition, state of combination, and solubility of soil ingredients. The elements, which most abound in soils, are not the most important. They contain the food of plants in but small proportions. If the soil is deficient in any of the constituents of plant food, or if they are locked up in inaccessible forms, plants will not grow, and the soil is said to be *barren*. If long cropping has removed any of the available constituents, it is brought to the same state, but is then said to be *exhausted*.

**1135. Two Sources of Plant Food.**—Plants live a double life. As will be explained in the following chapter, they have a twofold nutrition; deriving mineral food from the soil, and organic from the air. How much comes from each source is an important question in practical agriculture, and has given rise to a lively controversy among agriculturists. The atmospheric elements, carbonic acid, and ammonia may come also from the decomposition of organic matter in the earth, and the question at once arises, in fertilizing a soil, Which class of constituents is most necessary?

**1136. Variation of the Mineral Elements.**—While the organic constituents of plants are generally uniform, upon an examination of their ashes it is found that different classes are marked by the prevalence of certain mineral elements. Some abound in potash, others in lime; some in phosphates, and others in silica. Different parts of the same plant have also their predominating elements. We have here one reason why all crops are not suited to the same soil, and why one crop may succeed where another fails.

**1137. Liebeg's Mineral Theory.**—Starting from these facts, Liebig maintains that the fertilization of soils is chiefly a question of the addition of such mineral substances, in a form suitable for absorption, as plants specially require. He holds that the organic ingredients are abundantly furnished by the air, but that the

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properties. How are they influenced? 1134. What of their chemical properties? When are soils barren? and when exhausted? 1135. Explain the twofold life of plants. What question is in controversy? 1136 State the variations in the mineral elements. For what does this account? 1137. What is Liebig's mineral

mineral constituents are not supplied in sufficient quantity, and in available condition to the roots. Other chemists, represented by LAWES and GILBERT, of England, maintain the opposite view. They hold that the store of mineral substances in the soil is generally abundant for the wants of crops; but that the atmospheric supply is not, and requires to be supplemented by ammoniacal manures, or those yielding nitrogen to the plant.

**1138.** The truth seems to be, that while plants *if allowed sufficient time* can extract organic materials from the air, and attain a vigorous growth, yet if it be desired to rapidly increase their development, manures yielding ammonia and carbonic acid to their roots must be furnished. This policy, however, if long continued will exhaust the soluble inorganic constituents of the soil; hence in all permanent systems of agriculture, mineral fertilizers can no more be neglected than organic.

**1139. Lime as a Fertilizer.**—Fertilizers are divided into *mineral* and *organic*. Lime is one of the most important of the first class. It is used in the forms of marl and chalk, but most commonly as slaked lime. It acts in various ways, but its least important use is as plant food, for there are probably few soils which have not sufficient lime for this purpose. It acts mechanically to loosen tenacious soils, and chemically to decompose the silicates, liberating the alkalies, which are locked up in combination. It decomposes vegetable matters, converting their nitrogen into ammonia. It changes inert substances, so as gradually to render them useful to vegetation; decomposes noxious compounds; neutralizes baneful acids; sweetens vegetation, and improves the quality of nearly all crops.

**1140.** The compounds it forms in soils are generally insoluble; its action is therefore slow, often requiring two or three years to produce its full effect. At first it may diminish crops, and does so invariably when applied in over doses. On light soils, deficient in vegetable matter, it should be used sparingly.

**1141. Gypsum** is a valuable fertilizer for some crops, but the manner of its action is not known. Salts of potash, soda, and ammonia are excellent when they can be afforded. Experience verifies what theory affirms—that *ashes* are most valuable. They

theory? How is it controverted? 1138. What is said of organic and mineral fertilizers? 1139. Into what are fertilizers divided? Describe the uses of lime. What of it as plant food? 1140. Explain its action upon soils. 1141. What of

restore to the soil the mineral matters which the crops remove, while the alkali they contain has the same beneficial effect as lime, with the superior advantage of acting immediately. Crushed bones form an exceedingly valuable manure, as their animal matter yields nitrogen, and the mineral matter phosphate of lime. When bones are treated with sulphuric acid, a soluble phosphate is produced, which acts with more promptness than the neutral phosphate.

**1142. Farm Yard Manure.**—With the exception of the small portion retained in the body, it is evident that the excretions of an animal represent the complete composition of its food, and if all restored again to the soil, would afford the restitution necessary to prevent exhaustion and maintain fertility. The solid manure of animals consists of the indigestible and insoluble portions of their food. Liquid manure, on the contrary, represents the assimilated portion—that which was incorporated into the system, but was afterward decomposed and escaped from it in a soluble form. Liquid manure has, therefore, a far higher value as a fertilizer.

**1143. Guano** consists of the accumulated excretions of sea birds, deposited on rainless islands, and is sometimes found in masses a hundred feet deep. Its chief constituents are ammonia and phosphate of lime, which amount in the best kinds to from $\frac{1}{3}$ to $\frac{1}{2}$ its weight. They occur in a soluble form, and its effect upon crops is therefore immediate and powerful.

**1144.** The golden rule of agriculture is to restore to the soil, in the shape of manure, exactly what it has lost in the crop. By failing to heed this principle millions of acres of the choicest land in this country have been utterly exhausted, and millions more are undergoing the same ruinous process. The skilful farmer economizes every source of fertility. His manure heaps are sprinkled with gypsum, dilute sulphuric acid, or some other absorbent, to prevent the escape of ammonia; liquid excretions are preserved in tanks, and no particle of it wasted; compost heaps gather and utilize all forms of refuse, and while the accumulation of filth and noisome odors is prevented, the soil is enriched and culture made remunerative. Fertilizers are the farmer's motive power; with them he can do everything, without them nothing.

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gypsum salts of potash, &c. Ashes? Bones? 1142. Why is animal manure so valuable? Give the comparison between solid and liquid manures. 1143. What of guano? 1144. What is the golden rule of agriculture? How does the skillful

# PART IV.

# PHYSIOLOGICAL CHEMISTRY.

## CHAPTER XXVI.

### VEGETABLE CHEMISTRY.

### § I. *Chemical and Vital Forces.*

**1145.** Having noticed the properties of the chief organic compounds, we now pass to the chemistry of living beings, and the chemical relations of the organized kingdoms to each other and to the inorganic world.

**1146. The Mystery of Life.**—However viewed, the transcendent miracle of nature is LIFE. Whether considered as supporting the spiritual fabric of mind above, or as rooted in the inorganic world below, it is alike wonderful. Springing from ethereal airs and yet invincible; constantly perishing, and yet abounding in earth, air, and sea; forever conquered by death, yet evermore triumphant—'strongest and weakest of the things God has made,' it is not surprising that it has been regarded as unlike all else in nature. It was but natural that the living system should be looked upon as the seat of a potent agency—the mysterious *Vital Principle*—which built up, maintained, and used the organic form, and subdued all surrounding forces.

**1147. The Vital Force.**—There has been a reluctance to consider the science of organized beings from a chemical point of view, as it was said the vital force here comes into play which overrides

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farmer manage? 1145. What are we now to consider? 1147. Why has there been a reluctance to consider organized beings from a chemical point of view? Why is

chemical laws and is itself inscrutable. But this idea is no longer admissible. In one sense all forces are mysterious; yet they act with regularity, and whatever obeys law can be investigated. Though we cannot penetrate to the essential nature of any force, yet we may learn the manner of action and mutual connections of all forces. Vital force overcomes affinity, and so mechanical force overcomes gravity, but neither chemical force nor gravity is *suspended*. There are no unresisted forces in nature; indeed, it is only by their constant resistance and overcoming that forces are called into exercise.

**1148.** Vital force is not denied, but in the present state of science it does not mean an independent principle, or force, like heat, or magnetism; 'it is a collective term embracing all those causes upon which the vital phenomena depend' (LIEBIG). There are doubtless great obstacles in studying the changes of the living system, but as Prof. MILLER remarks: 'The difficulty depends not so much upon the obscurity which enshrouds the nature of life—for the essential nature of all forces is equally inscrutable, but rather upon the extreme delicacy of the arrangements by which such changes are effected, and which are liable to injury from a multiplicity of causes that have hitherto eluded scrutiny.'

**1149.** Having banished the superstition which blindly ascribed all things to an inscrutable vital force, and thus stopped inquiry at the outset, science has demonstrated that living beings are not aliens and exceptions in the universe, but parts of its wonderful plan; that they are governed by its laws, and are to be studied by the same methods, and with the same success, as the other phenomena of nature.

## § II. *Germination and Cell Growth.*

**1150. The Vegetable Embryo.**—Every plant springs from a seed, and every perfect seed contains the rudiment of a new plant, called the *germ* or *embryo*. In some varieties it is so complete that the microscope reveals its structure—root, stem, and leaves. The minute plant lies imbedded within the seed, surrounded by a protecting mass, which consists chiefly of starch and gluten.

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this idea inadmissible? How do forces operate? 1148. What is understood by vital force? From what arises the difficulty of studying the changes of the living system? 1149. What has science demonstrated? 1150. Describe the embryo. What

Fig. 292, shows the germ in Indian corn and its proportion to the surrounding matter of the seed, which forms the principal bulk of ordinary cultivated grains. Wrapped in this envelope, the embryo remains at the disposal of external agents. In certain conditions it continues at rest and torpid; but when these conditions are changed, it suddenly awakens from its slumber, puts forth a new power and begins to grow; this is called *germination.*

FIG. 292.

Germ of Indian Corn.

**1151. Chemistry of Germination.**—The embryo during growth derives its nourishment from the surrounding body of the seed. To convey this nourishment requires a moving medium. This office is performed by water; hence the first condition of germination is exposure of the seed to moisture, the absorption of which causes it to swell and increase in bulk. But the nourishment cannot be transferred except in a soluble form, and the starch and gluten are insoluble in water. To remove this difficulty nature resorts to a beautiful process which necessitates the second condition of germination—the access of air. Oxygen is thus absorbed, and acting upon the gluten, changes a minute portion of it into diastase, which, taking effect upon the starch, transforms it first into dextrine, or gum, and then into sugar. A portion of sugar is oxidized into acetic and carbonic acids—the temperature rising—and the remainder is transferred to the embryo. This is now assimilated by the germ, but it has no power to *organize* the elements which contribute to its nourishment. Heat also influences germination. Each kind of seed requires a certain temperature, although it varies in different species, from just above the freezing point, to 100° or 110°. Light impedes germination, the deoxidizing rays tending to *fix* the carbon and thus check the formation of carbonic acid.

**1152. Development of the Embryo.**—Fed by its store of nutriment, the embryo expands; one part, the *radicle*, shoots downward to form a root, while the other, the *plumula*, or stem, extends upward to the surface, as shown in Fig. 293. But when the stem appears above the ground, and expands its earliest leaves,

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does Fig. 292 show? When does germination take place? 1151. What nourishes the embryo during growth? Describe the first process of germination. The second. Of what power is the germ destitute? 1152. What are the radicle and plu-

the plant passes into another stage of existence, and a new order of phenomena is manifested. No longer depending for nourishment upon ready made food furnished by the seed, it begins to exert a formative power—the true vegetable function—and produce from the mineral elements of the earth and air such organized compounds as it may require.

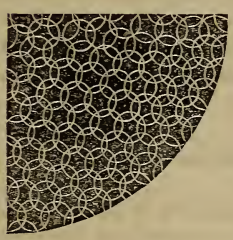
Fig. 293.

Developing Embryo.

**1153. Minute Mechanism of Growth.**—Vegetable growth takes place through the action of certain bodies termed cells, which are very minute, closed bags or sacs, usually ranging in size from $\frac{1}{25}$ to $\frac{1}{1500}$ of an inch in diameter. When uncompressed, as in the pith of elder, Fig. 294, or the pulp of fruit, Fig. 295, they have a rounded form; but when closely crowded by others, they become flat-sided, angular, and elongated, Fig. 296.

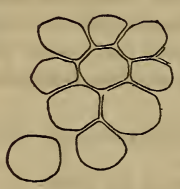
**1154. Structure and Formation of Cells.**— The cell consists of an outer membrane, or cell-wall, which incloses a lining sac, and within this is a dot or nucleus. In plants the outer membrane consists of *cellulose*, and the inner one of nitrogenous matter.

Fig. 294.



Cells of Elder Pith.

Fig. 295.



Cells of Fruit Pulp.

Fig. 296.

Cells of a Rootlet.

This contains a viscid, albuminous liquid called *protoplasm*, in which float numerous small grains. At the rupture, or death of the parent cell, these grains are set free, and each one becomes the germ or nucleus of a new cell. At its surface a delicate mem-

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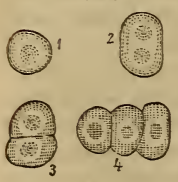
mula? How does the young plant now proceed? 1153. Describe the mechanism of growth. 1154. Explain the structure of cells. Their formation. How do they

brane appears, which gradually extends much beyond the original germ, giving rise to the cell cavity. Cells also multiply by division. The contents of the cell (1) become separated (2), and then a partition is formed across it (3) producing two cells; the subdivision is thus carried on indefinitely. Cells also increase, as before noticed, by process of budding and branching (1058). All the various tissues and structures of vegetables are built up of these cells, much as a wall is formed of bricks or stones; with the difference that the living structure forms its own bricks.

Fig. 297.




Growth of Cells.

**1155. The Cell Wall.**—Though the cell membrane is without the slightest trace of pores or openings, yet, like all organic membranes, it is permeable to fluids. The cell wall exhibits the remarkable property of retaining its liquid contents, while it permits the free transudation of other fluids. The passage of the fluids takes place by osmose. The terminations of the rootlets of plants consist of active cells which absorb water from the soil, and this, ascending through the fine woody tubes, passes through many millions of partitions before reaching the leaves.

**1156.** Cells are the little workshops of the organized world. By the free circulation of fluids, the raw materials are conveyed into them, and there transformed into organized matter. Different cells are specially adapted to produce different substances; some forming starch, others oil, wax, acids, &c.

## § III. *The Chemistry of Vegetable Growth.*

**1157. Architecture of the Tree.**—In speaking of germination, we saw that the embryo is stamped with a *polarity*—a tendency to develop in opposite directions; one part is to live in the earth, the other in the air. There is a deep significance in this architecture of the tree. Its stem, supported by widely-extended roots, rises high in the air; it divides into branches, and subdividing into boughs and twigs, finally terminates in myriads of little, flat, green plates, called leaves, which are generally mounted upon

multiply? 1155. How is the passage of fluids effected? 1156. What is the office of the cells? 1157. How does the germ exhibit polarity? What is said of the ar-

slender foot stalks. The idea evidently is to obtain the largest amount of surface which the material will afford consistent with the proper degree of strength. Furthermore, the atmosphere is ever in motion, so that by the swinging of the boughs, and the trembling of the leaves on their elastic foot stalks, the surface contact with the air is heightened to the utmost.

**1158.** Not without its purpose is all this admirable contrivance, and one might well anticipate that the economy of vegetation is in some way closely linked with the properties of the atmosphere. A microscopic examination of the leaf confirms this idea, by showing that its surface is covered by thousands of little openings (*stomata*), which are fitted either for the exhalation or inhalation of gases.

**1159. Food of the Plant.**—Water, containing dissolved a portion of the gases of the air—carbonic acid and ammonia—together with a minute proportion of earthy matter from the soil, is absorbed by the mouths of the rootlets (*spongioles*), and enters the vegetable organism as crude sap. In this dissolved form the mineral or inorganic world flows into the organic. The mineral solution, upon its entrance, mingles more or less with the organized juices, so that unmixed, crude sap is never found in the plant.

**1160. Nourishment from the Air.**—Rising through the capillary tubes of the vegetable structure, the crude sap passes upward to the leaves. It there exhales its excess of water into the air, becomes condensed and *digested;* new products are formed, and the sap is said to be *elaborated.* But the plant derives also a portion of its nourishment *directly* from the air, in the form of carbonic acid gas. Though the proportion of this gas in the atmosphere is small, yet the vast leaf surface—each leaf being covered by a film of moisture which is highly absorbent of carbonic acid—enables the foliage to withdraw it in considerable quantity from moving masses of air.

**1161.** The largest portion of the nutriment of the plant is, however, procured *immediately* from the soil. Carbonic acid, carbonate of ammonia, and nitric acid, are dissolved out of the atmosphere by the falling rain, and penetrating the earth, enter the plants

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chitecture of the tree? How is the surface contact heightened? 1158. Explain the design of this arrangement. 1159. How does the plant receive its food? 1160. What becomes of the sap? How does the foliage absorb carbonic acid? 1161.

by the roots. Should they be furnished to the roots by decomposition of organic matters in the soil, these again may be traced back to the air, so that although plants may be said to *receive* their food chiefly through the soil, they *derive* it from the air. The vegetable kingdom, and the atmosphere which surrounds it, consist of the same chemical elements.

**1162. Chemical Changes in the Leaf.**—The green leaves digest the crude sap; they consist of living cells, which carry on active chemical changes, translating matter from the inorganic to the organic state. It was shown by PRIESTLEY, in the last century, that the foliage of plants in the sunshine gives off oxygen gas to the surrounding air. This may be seen by exposing a few fresh leaves to the sunshine in an inverted glass vessel, filled with water, Fig. 298; the air bubbles which arise and collect at top are oxygen. Carbonic acid thus enters the leaf, and oxygen is set free, the carbon being retained. The leaves decompose the carbonic acid, separating the carbon, which is *fixed* in newly-formed organic compounds. This is probably the source of all the carbon in plants.

FIG. 298.

Leaves Exhaling Oxygen.

**1163.** Water and ammonia are decomposed to furnish the hydrogen and nitrogen of organic substances; the requisite oxygen being supplied by both carbonic acid and water. From these elements the leaf constructs gum, dextrine, starch, albumen, cellulin, and many other products which are contained in the elaborated sap, and conveyed to different points of the vegetable organism.

**1164.** Plants are thus universally instruments for separating oxygen—machines of *deoxidation*. It is through these operations, and by grouping the products thus formed, that the plant becomes a constructor of organized bodies.

**1165. Formation of Acids.**—How the changes take place we do not actually know, but it is not difficult to see in what way they are probably performed. The atom of carbonic acid may be taken as the starting point. It consists of three elementary atoms,

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What is said of the nourishment of the plant *immediately* from the soil? 1162. what was proved by PRIESTLEY? How may it be shown? Describe the chemical changes? 1163. Explain the further processes of the leaf. 1164. How does the plant construct organized bodies? 1165. How are acids supposed to be

one of carbon, and two of oxygen. *No part of a vegetable or animal structure contains for one atom of carbon more than two atoms of another element*—most of them contain less. Organization therefore begins by separating oxygen from carbonic acid. The vegetable acids are lowest in the organic scale, and arise from the first steps of deoxidation. For example, carbonic acid consists of $CO_2$, or COO, and dry oxalic acid of $C_2O_3$, or $\frac{CO}{COO}$. If, therefore, from a group of two atoms of carbonic acid, but a single atom of oxygen be separated, the remainder represents oxalic acid.

**1166.** The process may now be carried a step higher, resulting in the formation of a more complex acid. If from a group of two atoms of oxalic acid two more atoms of oxygen are removed, and the hydrogen from the two atoms of water added, we have *malic acid* $C_4H_2O_4$. To produce an atom of oxalic acid, but a single atom of oxygen is set free; for an atom of malic acid, six are liberated.

**1167. Production of Sugar, Starch, &c.**—The products first formed are marked by an excess of oxygen, like carbonic acid, and have properties analogous to that acid. But as the process is carried farther, a higher and neutral class of bodies appears—the acids pass into sugar and its congeners. To produce an atom of sugar an atom of carbonic acid is taken, COO; half its oxygen is separated, making CO; an atom of water is then decomposed, and its hydrogen made to replace the separated oxygen atom, thus COH. Twelve atoms of carbonic acid, and twelve of water, changed in this manner, give $C_{12}H_{12}O_{12}$, or the glucose group without its combined water.

**1168.** It has been stated that this class of bodies, sugar, starch, cellulin, &c., are remarkable in having their oxygen and hydrogen in the exact proportion to form water, so that they may be regarded as hydrates of carbon. On this view we have but to suppose *all* the oxygen removed from the carbonic acid, and the resulting carbon joined directly to water, to explain the synthesis of these substances. It will be noticed that the deoxidizing process is carried much farther here than in the case of acids: to produce an atom of sugar, $C_{12}H_{12}O_{12}$, 24 atoms of oxygen are set free.

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formed? Example. 1166. How the more complex acids? 1167. What is said of the products first formed? What class now appears? How are they produced? 1168. Give the synthesis of the bodies. 1169. Describe the formation of fats and

**1169. Production of Fats and Oils.**—As these bodies contain an excess of hydrogen and a minimum of oxygen, being thus the reverse of acids, it is obvious that the deoxidizing process has been here carried much further. For the production of an atom of stearine, $C_{114}H_{110}O_{12}$, 144 atoms of carbonic acid and 98 of water must lose their oxygen, which would liberate no less than 326 atoms of this gas. In forming the pure hydrocarbons, the reduction of hydrogen and carbon is complete, all their oxygen being set free.

**1170. Production of Nitrogenous Compounds.**—The formation of these is perhaps less simple. The large proportion of carbon and hydrogen is of course obtained by deoxidation. But the complex albuminous group is probably built up by the *coupling* of simpler compounds (923). It is supposed that all the higher or more complex organic compounds are thus formed; and 'albumen, casein, and the organic bases are regarded as coupled compounds, which they certainly are, although we do not yet know the copula belonging to them' (Liebig).

**1171. Changes of the Starch Group.**—Physiologically, dextrine, sugar, starch, and cellulin are one thing. Several of their modifications are strictly isomeric, and they are all convertible into each other by the addition or subtraction of an atom or two of water. In a chemical point of view they might all be formed in the leaf with equal ease; but their diversities of physical character require their production in a certain order. Dextrine, gum, and sugar are probably first formed in the elaborated sap. These are soluble, and therefore easily transported from point to point of the vegetable organism. Cellulin is the fixed, insoluble member of the group, and, therefore, cannot be produced at first; it is only formed where it is required to furnish tissue. Starch is a kind of intermediate product; being insoluble, and taking the shape of minute grains, it is fitted to be temporarily deposited as a kind of nutritive stock, to be redissolved and transferred to other places for use, wherever necessity requires. We saw an example of this in the case of germination. Starch is the form in which the food for the future embryo is stored up in the seed, to be transformed into dextrine and sugar, and then again into the cellulin of the young germ.

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oils? What is said of the pure hydrocarbons? 1170. How are the nitrogenous compounds formed? 1171. How are dextrine, sugar, starch, and cellulin regarded chemically? When are dextrine, gum, and sugar formed, and why? Cellulin?

**1172. Changes of the Albuminous Group.**—In the living cell the nitrogenous protoplasm seems to be the active agent, or medium of vital changes. We saw its power of inducing transformation in the starch group, when treating of fermentation. It forms the lining of the cell, and the cellulin is deposited under its influence to form the permanent wall or cell fabric. When the cell is thus matured, its nitrogenous matter leaves it and is attracted onward into the newly growing parts. It is thus explained why so small a quantity of albuminous substance plays so all-important a part in the vegetable economy, and why such a mere trace of it is found in the woody structure of plants. The matured heart of trees yields but the faintest indication of nitrogen, while the sapwood and young growing parts always contain a small proportion, which accounts for their tendency to rapid decay. These substances are at length nearly all withdrawn from the fabric of the plant, and laid up in the fruit and seed. Being transferred to the animal system, their relations are changed, and they play the same part that the starch group did in the vegetable structure.

**1173. Plants in Apartments.**—As plants are purifiers of the air in a double sense, withdrawing its noxious carbonic acid and returning its life-giving oxygen, it might seem that they would be very efficacious for this purpose in inhabited rooms. They perform this office in the day time, and are also useful in exhaling moisture into the air, which, in houses warmed by hot air, is often a most important service. But at night the regular vegetable function is suspended; carbonic acid is no longer withdrawn; oxygen is no longer set free, and the effect of the plant upon the air is due to *leakage* through the leaves of the gaseous contents of the sap. Carbonic acid will therefore be given off in very small amount at night, and just to that degree, vegetation is injurious in sleeping rooms. It is erroneous to speak of plants as *respiring*—exhaling oxygen by day, and carbonic acid by night.

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What of starch? 1172. Describe the office of the protoplasm. What is said of the nitrogenous matter? Why does the sapwood and young growing parts decay rapidly? What further changes do the nitrogenous bodies undergo? 1172. What office do plants perform in the daytime? What change occurs at night? To

# CHAPTER XXVII.

## DYNAMICS OF VEGETABLE GROWTH.

### § I. *The Forces of Organization.*

**1174.** In the preceding paragraphs we have confined our attention to the material changes of vegetable growth; we are now to regard it under the dynamic aspect, and take account of the forces brought into play.

**1175. Hypothesis of Latent Vitality.**—Before the establishment of physiological science upon its present inductive basis, when everything was quickly explained by the assumption of an all-powerful vital principle, it was held that the germ was *potentially* the tree; that is, that all the vital energies of a vast vegetable organism which had been growing perhaps for hundreds of years, prëexisted in the embryo in a dormant state, and that the growth consisted only in the waking up of this latent vitality. This absurd doctrine was long since replaced by the kindred notion that vital force exists in a dormant condition, not alone in the germ, but in all matter capable of becoming organized; that the germ, in attracting to itself the materials of growth and incorporating them into the living structure, only calls into activity their latent powers, and that the forces, heat, light, &c., are but vital stimulants which arouse the torpid energies of carbon, oxygen, hydrogen and nitrogen; the growing cell appropriating the vital force thus set free.

**1176. Later Views.**—The progress of our knowledge of forces has swept away these assumptions, and shown that the same intelligible and beautiful principles which we have found in the inorganic world, extend also to the organized kingdom; that the plant is no anomaly in nature, but a link in her vast chain of activities, and only to be understood in connection with the universal scheme. The career of the plant is a constant and admirable illustration of the great laws of the conservation and correlation of forces. It is now considered that, as the plant absorbs matter from the surrounding world, so it also absorbs force, and as it changes and assimilates that matter into organized and vital forms, so it also

what extent are they injurious? 1174. How are we now to consider vegetable growth? 1175. What was the old hypothesis of latent vitality? By what was it replaced? 1176. What does our knowledge of forces show? Of what is the career

assimilates or converts surrounding forces into organized or vital force. Not that the plant deals with matter and force separately, for they are inseparable; but in appropriating matter it appropriates also the forces of which it is the medium.

**1177. Storing of Forces in Nature.**—Conditions of matter represent quantities of power. The solid state contains the least; the force that melts it is stored up in the liquid; while the gaseous form represents a still higher condition of power. These forms of matter resemble springs coiled up to successive degrees of tension: when relaxed they give back their force. Ice is like the relaxed spring; water like the spring partially bent, and steam like the spring strained to a much higher tension. As the vapor relaxes into water, it gives out the force of elasticity; as it still further relaxes into ice, it gives out the force of liquidity (280).

**1178. Organic Bodies Reservoirs of Power.**—Organic substances, like bent springs, are stores of force, and represent the power expended in separating and grouping their atoms. According to the extent of the organizing process, is the force stored away. In acids it is least; in the starch group it is higher, and in the hydrogenated group highest. As the three states of matter constitute three reservoirs of power, the solid lowest, the liquid higher, and the aëriform highest, so organic bodies may be regarded as a fourth reservoir still higher. Organic substances may fall directly to the mineral state, as in open combustion, when their force is all given out at once in the intense form of heat and light; or they may descend by the slow steps of decay, when the force is gradually released; or again, they may be transferred to the animal system, and give out their power as animal force: but in all cases the force produced is precisely the same in amount.

**1179. Source of Germinal Force.**—The economy of the plant is to *store*, and not to *expend*. It is *fixed;* that is, it never consumes force by locomotion, and never draws upon its constantly accumulating stock, except in time of flowering. In germination we saw that the embryo is nourished by the stored material of the seed. But to effect the transformation and carry on new growth, force is required, and this is furnished by destruction of a portion

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of the plant an illustration? Describe its mode of action. 1177. How are forces stored in nature? Give the comparison used. 1178. What is said of organic bodies in relation to force? Examples. How may they be regarded? In what ways may they lose their force, and what of its amount? 1179. What is the func-

of the organized substance of the seed. The part destroyed gives up its force, to be reconsumed by the growing embryo, so that the plantlet at first draws upon its prepared stock of force, as well as of matter.

**1180. Transferrence of Organic Force.**—Nature furnishes many other illustrations of this principle, in which the forces released in dissolution are immediately utilized in evolution. The yeast plant accompanies putrefaction: so the 'mould' that appears upon damp, decomposing bodies, and the fungi that grow upon decaying wood, are lower forms of growing vegetation. Thus organization springs directly from disorganization. As the fall of one arm of a balance raises the other, so the descent of organized atoms to the mineral state gives out the force required to raise other atoms to the like condition.

**1181. Influence of External Forces.**—When its store is consumed, the embryo opens its leaves to the air and light, and commences to form organic matter out of mineral substances. This requires a vast expenditure of power, for which there is no source but the forces of the external world. These are spent in producing growth, and are stored up as vital force of the vegetable organism. According to the intensity with which these forces act, is the vigor of growth. In the tropics, where the temperature is high, vegetation is rank and luxuriant, and tribes of plants abound which can flourish only in torrid regions. Leaving the equator, and proceeding north or south, vegetation becomes less rich, and new varieties of plants appear with the declining temperature. Going still farther from the equator, as the forces diminish in intensity the vegetation becomes still more scattered and meagre, and toward the poles entirely disappears. The abundance of substances which plants produce declines also in the same order. Tropical plants abound in various aromatic, medicinal, and coloring compounds, which are not yielded by those of higher latitudes.

**1182.** Again, in ascending mountains, the same remarkable phenomena are observed. Leaving tropical gardens at the base, we may, in a single day, ascend to the line of eternal snow, cross-

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tion of the plant? From whence does it obtain force? 1180. Give examples of the transferrence of force. What of organization? 1187. Describe the action of the embryo. Where does it obtain vital force? What determines the vigor of growth? How is this illustrated? What is said of the substances produced by plants? 1182. Give further examples. What is thus proved? 1183. State the re-

ing belts of vegetation corresponding to those between the equator and the poles. Moreover, in extreme northern regions, where the sun shines uninterruptedly for three months and a half, the low temperature and brevity of the season are compensated by the constant action of the solar forces, causing the vegetable world to spring into life as if by magic. That the quantity of force in action determines the quantity of organization, is thus proved on the most stupendous scale.

**1183.** The same fact is further illustrated in the growth of different varieties of plants. BOUSSINGAULT found, as a result of numerous observations, that from germination to maturity the same annual plant receives very nearly the same amount of heat, whether grown in the temperate latitudes, or in the tropics. If the mean temperature is low, it will require more days to ripen than if it were high.

**1184. Vast Force Exercised by the Leaf.**—When we look upon the luxuriant foliage of the tree, we cannot fail to be impressed with its beauty, but we hardly suspect that those leaves which flutter so lightly in the breeze are engines for the exercise of enormous power. Yet such is the fact, for *they decompose carbonic acid.* The atoms of a pound of carbon rush into union with those of oxygen—they fall down the chemical precipice with a force sufficient to raise a thousand weights each of a thousand pounds, one foot high. This expresses the strength of their attraction for each other, and if they are to be separated, this amount of force must be again expended. So powerfully are the elements of carbonic acid held in combination, that the chemist can only separate them by the double action of a high heat and the most powerful affinity; even then, only the carbon is set free, the oxygen remaining in a state of combination. But what no chemist has ever been able to accomplish, is effected by every green leaf and every humble blade of grass;—they decompose carbonic acid *at common temperatures*, retaining the carbon and *setting the oxygen free.*

**1185. Motive Power of the Plant.**—But the leaf cannot *create* the power it exerts. Though a chemical engine of wonderful efficiency, it is no more self-moving than the steam engine, or

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sult of BOUSSINGAULT'S researches. 1184. What proves that leaves are engines of vast power? Describe the force with which carbon unites with oxygen. Compare the power of the chemist and the leaf. 1185. What cannot the leaf do?

the water wheel. Its motive power is the sunbeam; and as the steam engine moves at a rate proportional to the amount of steam supplied, and ceases to go at all if the steam is cut off, so the leaf performs its work at a rate proportioned to the intensity of the light which falls upon it, and ceases to act if it be withdrawn.

**1186.** In total darkness plants cannot grow; if there be but little light, they are white, watery, and sickly; and even in the shade, as all have observed, they are feeble and dwarfed. The leaf can only decompose carbonic acid *in the day time*. Plants, of course, grow at night; cells multiply and transform materials constantly, but the initial act of organization upon which all else depends, *the separation of carbon from oxygen*, only takes place under the influence of the light of the sun.

**1187. The Organizing Region of the Spectrum.**—To what portion of the complex ray is assigned the task of effecting the chemical changes of the leaf is an interesting question. Heat, though largely absorbed in the organizing process, does not produce this effect. It was formerly attributed to the chemical, or actinic force, but the admirable researches of Dr. DRAPER proved that this view was erroneous. He placed some green leaves in tubes of carbonated water, and so arranged them in the several colors of the spectrum as to ascertain, from the amount of carbonic acid absorbed and of oxygen liberated, how the decomposing force is distributed. The result proved that the change takes place most actively in the yellow, orange, and green colors. At the extremes of the spectrum, in the region of greatest heat and greatest chemical effect, the action was very feeble, or altogether wanting, while the amount of change corresponded to the intensity of the illumination.

## § II. *Chemistry of the Sunbeam.*

**1188.** In classical fable we are told that Prometheus stole a spark of celestial fire and warmed into life the earthly body he had formed. The mythologic dream was parallel with the truth of nature;—the true Promethean spark is the *Sunbeam*, which, by

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What is said of its motive power? 1186. How is this proved? How does the action of leaves during the night differ from that under sunlight? 1187. What question is stated? Describe Dr. DRAPER'S experiment. What did it prove?

its wonderful alchemy transforms dead matter into organized and living forms.

**1189. Extent of Solar Influence.**—Not only life, but all the grand phenomena of force with which we are familiar upon this planet, have their origin in the sun. His radiations govern the movements of terrestrial atoms, and in *these* the movements of masses take their rise. Should that body cease to give out emanations, the earth would speedily lose its heat; life would disappear, vapors condense, and liquids congeal. There would still be tidal influence, due to the attraction of the dark masses of the sun and moon, but, as the ocean would be solid, there could be only a slight movement in the atmosphere. There might also be volcanic force, due to the earth's central heat, although this too has been held as subject to astronomic agency.

**1190. Effects of Solar Heat Alone.**—Were the sun to radiate *heat alone* the earth would still remain dark, but the oceans would melt, and tides begin to lash the coasts. The atmosphere would be rarefied unequally as now; storms would arise, and there would be the motive power of wind. Water would be converted into vapor, and condensed into invisible clouds and rain. Streams would channel their way to the sea, and falling in cataracts, would give rise to water power. The descending floods, bringing down the sediment, would gradually lower the continents and fill up the oceans, while the tides would gnaw away the shores; the distribution of land and water would be changed, and there would be all the extensive effects of aqueous, geologic agency.

**1191.** Furthermore, the electrical conditions of matter would be disturbed; tropical tornadoes, and the milder storms of the temperate latitudes would be accompanied with thunder and lightning; the unequal heating of the earth in its daily rotation would give rise to thermo-electric currents, and these would produce magnetism. All these results would flow from solar radiations quickening the motions of earthly atoms, so that ice would change to water, and water to vapor.

**1192. Effect of Increased Solar Action.**—If we again suppose the energy of solar radiation so exalted that light is emitted with heat, the higher phenomena of organization become possible.

1188. What is the true Promethean spark? 1189. State the extent of solar influence. What would follow if the sun should cease to emit rays? 1190. What if it should radiate *heat alone*? 1191. Mention further results. 1192. What would be

With the introduction of plant germs, the vegetable world would be called into being by the vitalizing chemistry of the sun. The animal world, dependent upon the vegetable—consuming its matter and its force—could then appear with all its multitudinous forms of power. The burning of wood and coal would also give steam power. Thus, in addition to all the forms of mechanical movement upon earth, its very energies and impulses of life originate in the sun.

**1193. The Organic Kingdom a Magazine of Force.**—The vegetable world, born of the atmosphere, consists of condensed gases. The animal world, derived from the vegetable, is also but solidified air. So the food that we consume, the clothes that we wear, the houses in which we live, the fuel that warms us by the fireside—that transports us to distant places with lightning speed, and labors for us in a thousand ways, are all nothing but condensed air. The sunbeam is the agent of condensation, and thus the organic world presents itself as a vast magazine of solar force.

**1194.** So the coal deposits—the carbonized remains of a vegetation which flourished long before man appeared upon the globe, were condensed from an atmosphere richer in carbonic acid, and perhaps by a more brilliant sun, and yet, this coal, having slumbered in its ancient bed through uncounted eras of time, now comes forth to surrender its ethereal agents, light and heat, and return as carbonic acid to the air from whence it came.

**1195. The Sunbeam the Antagonist of Oxygen.**—When treating of oxygen it was stated that this element enshrouds the globe and tends to unite with and bring all things to rest, so that if the earth were left to the action of its own forces, life would quickly disappear, and leave the world a desert. But the earth's vegetation is the beautiful instrumentality by which this action is arrested. The leaves extract poisonous carbonic acid from the air, deprive it of the elements it had seized, and return it again to the atmosphere, while the forces which impel these changes are the beams of the sun. These are the great antagonists of oxygen. Under its influence organized matter is rent into its elements and carried down to the mineral world; under the influence of the solar rays it is again raised to the organized condition. If oxygen

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the effect if light accompanied heat? What thus originate in the sun? 1193. How is the organic world a magazine of force? 1194. What is said of coal? 1195. What would be the influence of oxygen uncontrolled? How is its action ar-

dilapidates they renovate; if that decomposes and breaks down, *they* construct and build up; if that is seen in the falling leaf of autumn, *they* are proclaimed in the exuberant foliage and blossoms of spring. If oxygen is the mainspring of destruction, wasting, burning, consuming all things—the solar rays constitute the mighty force of counteraction. They reunite the dissevered elements, and substitute development for decay, calling forth a glory from desolation, and life and beauty from the very bosom of death.

**1195. It is the Motive Power of the World.**—Thus is the earth warmed, illumined, magnetized, and vivified by the sun. In the fall of the avalanche, the roar of the cataract, and the flow of rivers—in the crash of thunder, the glare of lightning, and the sweep of tornadoes—in the blaze of conflagration, and the shock of battle—in the beauty of flowers, of the rainbow, and the ever shifting clouds—in days and seasons, the silent growth of plants, and the elastic spring of animals—in the sail-impelled or steam-driven ship, and the flying train—in the heavy respiration of the laboring steam engine, and the rapid click of the telegraph; in all the myriad manifestations of earthly power, we behold the transmuted strength of the all-energizing sun.

**1196. Amount of Solar Radiation.**—And yet the entire power displayed upon the globe is as nothing compared to the vastness of of its source. The earth arrests but the $\frac{1}{2,300,000,000}$ of the whole amount of force that the sun emits. The total heat received by the earth would be sufficient to boil but 300 cubic miles of ice-cold water per hour, while the entire amount radiated by the sun would boil 700,000 million cubic miles of ice water in that length of time. The sun is 1,400,000 times larger than the earth, yet the force generated upon each square foot of his surface is equal to 7,000 horse power per hour.

**1197.** Stupendous as is this scale of power, it again sinks into insignificance, when we remember that our sun is itself a star —that it is but one of the countless millions of suns which fill the immeasurable spaces;—each a fountain of energy of the same nature as that around which we revolve, and upon which we more immediately depend. Thus in the strictest sense the earth borrows its life from the stars.

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rested? Describe the opposite action of oxygen and of the solar rays. 1195. How is the sun the motive power of the world? 1196. State the amount of solar radiation the earth receives. How does this compare with the entire amount radiated? 1197. What fact renders this amount of force comparatively insignificant? State

**1198. The Universe Culminates in Life.**—If Astronomy has revealed to us a universe of unspeakable grandeur, Chemistry has linked the mighty mechanism to the course of terrestrial life. She teaches us not only that the leaves and flowers are distilled from the crystal medium in which they dwell, but that they are tissues woven in the loom of the universe—their warp the subtlest ethers of earth, their weft the radiations of the stars: not only that the leaf is the crucible of vitality, whose mysterious alchemy is interposed between ourselves and death, but that it is the wondrous mechanism appointed to receive and gather the life forces which God is perpetually pouring through His universe.

**1199.**—It is a fine suggestion of HUMBOLDT that if we could imagine those movements of the stellar universe which take place in long periods to be compressed into a short space of time, and were we endowed with telescopic vision to behold them, we should then vividly realize that there is nowhere such a thing as rest. The stars which we term *fixed* would be seen all in motion; constellations drawing together; clusters unfolding and condensing; nebulæ breaking up and universes melting away—*motion* in every part of the vault of heaven. Could we then be permitted to gaze into the living organism upon earth—plant, or animal—we should behold a kindred spectacle; the constituent atoms in ceaseless movement—combining and separating—groups dissolving and rearranging, and all circulating in orderly and determined paths—*movement* in every point of the vital organism. Thus the motions of the everlasting suns, shot in radiant forms across the universe, reappear in the movements of organic beings. The unity of the scheme is unbroken—the harmonies of earthly life are but cadences of the 'music of the spheres.'

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the nature of celestial radiations. 1198. What is said of Astronomy and Chemistry? What does the latter teach us? 1199. Mention the suggestion of HUMBOLDT. What should we see in the heavens? What upon the earth, if we could gaze into the living organism? How is the unity of the scheme preserved? 1200.

# CHAPTER XXVIII.

## ANIMAL DIGESTION.

### § I. *Changes of Food in the Mouth.*

**1200.**—Matter organized by the plant is consumed by the animal to form its fabric and maintain its functions. It is to be converted into blood, the source upon which the whole system draws for whatever it requires; but for this purpose food must be completely transformed. No one element of diet contains all the necessary materials for the use of the adult; various articles must therefore be mixed. Some of the elements of food are incapable of forming blood—these require to be separated. To effect these important changes in food is the great purpose of *digestion*, which may be divided into three distinct and successive stages.

**1201. Necessity of Saliva.**—As in chemical analysis the first step consists in crushing to powder the materials to be acted upon, so, at the threshold of the digestive process, we find an admirable contrivance for crushing and reducing the food. It consists of a double system of teeth, so placed and shaped as to combine cutting, crushing and grinding, through vertical and side movements of the lower jaw, and made to work against each other by powerful muscles. But no amount of mechanical action alone can liquefy solid aliment. To do this a solvent is required, and this office is performed by the *saliva*, which is separated from the blood and poured into the mouth by three pairs of glands.

**1202. Properties.**—The salivary juice is a faintly blue, glairy liquid, readily frothing. In health it is always alkaline, from the presence of salts of soda, potash and lime, but its alkalinity increases during and after meals, while in prolonged fasting it becomes almost neutral, and in some inflammatory diseases it is acid. It contains an organic principle named *ptyalin*, an albuminous substance very prone to putrefaction. The *tartar* which collects upon the teeth is the residue left by evaporation of the water of the saliva, and consists of earthy salts cemented together by animal matter.

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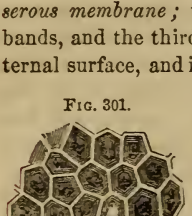
What is said of food in connection with blood? State the purpose of digestion. 1201. What of the teeth? What is the office of the saliva. 1202. Mention the properties of the saliva. What is ptyalin? Tartar? 1203. Uses of saliva? Give an

**1203. Uses.**—Saliva serves to lubricate the mouth and moisten the food, so that it may assume the pasty condition. It is indispensable to the sense of taste, as all food is tasteless which the saliva cannot dissolve. It also begins the operation of digestion. It converts starch into sugar, and sugar into lactic acid. If a little pure starch be chewed for a short time, it will become sweet; a portion of it has been changed to sugar. The importance of thoroughly masticating our food, especially the starchy kind, is thus apparent. Saliva exerts no digestive action upon the nitrogenous aliments.

## § II. *Changes of Food in the Stomach.*

**1204. Structure of the Stomach.**—The masticated food is carried by the act of swallowing (deglutition) into the *œsophagus* (gullet), which conducts it downward into the *stomach*. This is a pouch-shaped enlargement of the digestive tube, with the form shown in Fig. 303. The capacity of the human stomach varies, but on an average, when moderately distended, it will hold about three pints. Its walls consist of three coats; the outer is known as the *serous membrane;* the middle consists of two layers of muscular bands, and the third is the *mucous membrane*, which lines its internal surface, and is of much greater extent than the outer coats.

FIG. 301.



Inner Coat of Stomach, magnified.

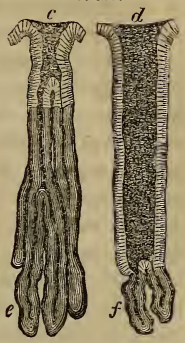
**1205. Mechanism of Secretion.**—When the lining membrane of the stomach is magnified about 70 diameters, the mucous membrane exhibits the honeycomb appearance seen in Fig. 301. Into these reticulated spaces there open little cup-shaped cavities called *stomach follicles*, which are about $\frac{1}{200}$ of an inch in diameter. Fig. 302 represents the magnified secreting follicles from the stomach of a dog; *c d* the mouths opening upon the surface; *e f* the closed tubes imbedded in the membrane below. The walls of these cavities are webbed over with a tissue of most delicate blood vessels, carrying streams of blood; a network of veins surrounds their outlets upon the surface of the membrane, while nerves innumerable pervade the whole arrangement.

**1206.** The office of these follicles is to separate from the blood

example of its digestive power. 1204. Describe the stomach. 1205. Explain the

the digestive fluid of the stomach. This is done by cell growth. At the bottom of the cavities, in the little tubular roots, cells arise in immense numbers. Nourished by the blood, they multiply and swell until they are driven up in crowds to the surface, where they burst and deliver their contents into the stomach.

Fig. 302.




Stomach Follicles.

**1207. The Gastric Juice** is a limpid, colorless, and always distinctly acid fluid, secreted by the cells of the stomach follicles. Its acidity is chiefly due to chlorohydric acid, though lactic acid is commonly present. It contains a nitrogenous body called *pepsin*, or ferment substance, of which but little is known. Liebig does not consider it as a peculiar digestive agent, but as formed of minute parts of the mucous membrane of the stomach, separated and in a state of decomposition. This substance, acted on by the oxygen swallowed in the frothy saliva, excites the digestive fermentation attributed to pepsin. The composition of the gastric juice varies in different kinds of animals, and seems adapted to different kinds of food.

**1208. Its Action.**—If coagulated white of egg be placed in water acidulated with chlorohydric acid, no solvent action takes place at common temperatures for a long time, though at 150° a slow dissolving effect begins. But if a little pepsin be added to the liquid, the solution goes on actively. An ounce of water, mixed with twelve drops of chlorohydric acid and one grain of pepsin, will completely dissolve the white of an egg in two hours at the temperature of the stomach. It acts in the same manner on cheese, flesh, and the whole nitrogenous group, but has no solvent power on non-nitrogenous matter. Gastric juice, withdrawn from the stomach, produces the same effect, though by no means so rapidly as in the stomach.

**1209. Peptones.**—In digestion nitrogenous matters are not only dissolved, but *remain* dissolved. They seem to be modified in some peculiar way, and to this state the name *peptone* has been applied; thus albumen produces an albumen peptone; fibrin a

mechanism of secretion. 1206. Its action. 1207. What is the gastric juice? How does Liebig regard pepsin? 1208. Describe the action of the gastric juice. 1209.

fibrin peptone, and casein a casein peptone—substances which continue dissolved after the solvent is withdrawn. The presence of oily substances has been shown to be essential to the formation of these products, and therefore to stomach digestion.

**1210.** The quantity of gastric juice secreted is very large. The hourly destruction of fibrin throughout the system in average muscular action has been assumed as 62 grains, and it has been found that 20 parts of gastric juice dissolve one part of dry nitrogenous matter. To digest this quantity, some 60 or 70 ounces are required. It is, however, questionable whether the gastric juice is sufficient to dissolve all the nitrogenous matter required for the system.

**1211. Motions of the Stomach.**—The food, as it enters the stomach through the cardiac orifice, Fig. 303, is immediately subjected to a peculiar movement, by which it is thoroughly intermixed with the gastric fluid. This motion is produced by the alternate contraction and relaxation of the muscular bands, which produce a constant agitation or churning of the alimentary mass. These contractions cause the food to revolve round the interior of the stomach in from one to three minutes, but as chymification advances, the rapidity of the motion is increased. The combined effect of the agitation and of the mingled solvent is to reduce the solid food to a uniform pulpy, semi-fluid mass called *chyme*.

**1212. Limit of Stomach Digestion.**—The opinion long entertained that the stomach is the exclusive seat of digestive changes, is now abandoned. We have seen that foods are divided into two great classes, based upon essential differences of chemical composition, viz.: the nitrogenous and the non-nitrogenous. This distinction reappears in digestion. So different are these two kinds of aliment that they require totally different, nay opposite agents to dissolve them. Digestion commences in the mouth with an alkaline liquid upon the non-nitrogenous portion of the food; proceeding to the stomach, it meets an acid; the changes begun in the mouth are arrested; the alkaline saliva is neutralized, and action begins on the nitrogenous compounds.

**1213. Absorption from the Stomach.**—The liquefied food enters the circulating vessels by absorption, and passes into the

What of peptones? 1210. What is said of the quantity of gastric juice secreted? 1211. Describe the motions of the stomach. What is *chyme*? 1212. Is the stomach the sole seat of digestion? What of the nitrogenous and non-nitrogenous foods in

blood. This is proved by the fact that when the outlet of the stomach is closed by tying it, water which has been swallowed disappears rapidly from the organ, and medicines act upon the system almost as promptly as under natural circumstances. In the same way portions of sugar, lactic acid, and digested nitrogenous substances, pass into the blood by absorption through the stomach veins. The remainder of the contents gradually oozes through the valvular opening that leads into the intestine.

**1214. Why the Stomach does not Digest Itself.**—To the question often asked, Why the gastric secretion does not dissolve and digest the stomach itself, it has been triumphantly replied that the 'vital force' of the living stomach prevents such a result. But BERNARD and others have proved that the vital force offers no such resistance. On inserting the hind legs of a live frog into the stomach of a dog, through a fistulous opening, the flesh is almost as rapidly dissolved as though it did not belong to a living animal. The resisting power of the stomach is due to a sheath of mucus, and to the continuous formation of protecting cells, called *epithelium*, during the process of digestion.

## § III. *Third Stage of Digestion.*

**1215. Intestinal Digestion.**—The partially digested food, dismissed from the stomach, enters the *duodenum*, or first portion of the intestinal tract, where the process is finished. The general scheme of the digestive tract is represented in Fig. 303. Into the duodenum two small tubes or *ducts* open; one leading from the liver and pouring in *bile*, and the other from the pancreas yielding *pancreatic juice*, the first being much larger in quantity.

**1216. The Bile** is formed in the liver from the venous or dark blood, and is accumulated as *gall* or *cystic bile* in a sac called the *gall bladder*. Human bile is a bitter, yellowish-green, ropy liquid, of a nauseating odor. Its viscidity is due to the presence of mucus from the gall bladder, which gives it a tendency to putrefaction. Bile contains a small proportion of nitrogen and a notable amount of sulphur. In constitution it may be regarded as a species of soap—a combination of fatty acids with alkalies.

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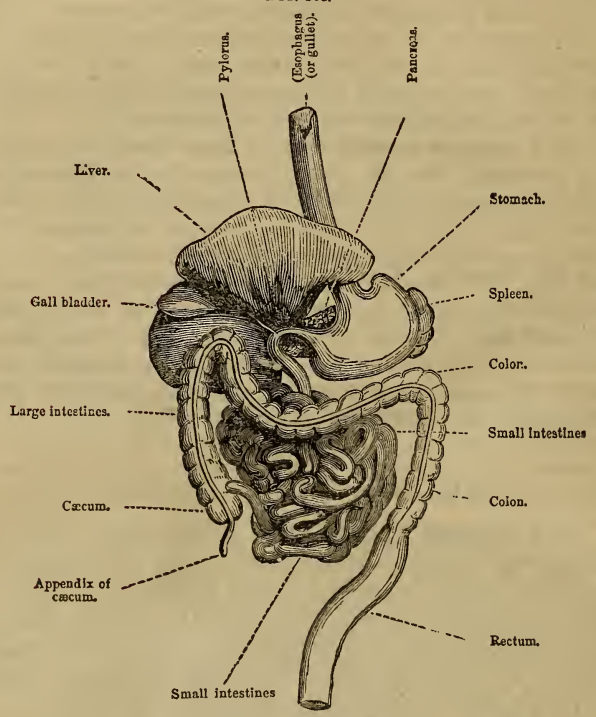
relation to digestion? 1213. How does food enter the blood? State the proof. 1214. Why does not the stomach digest itself? 1215. Describe intestinal

**1217.** Ox bile consists of two resinous acids combined with soda; the *cholic* and *choleic* acids. *Taurin* is a highly sulphurized

FIG. 303.




Digestive Tract in Man

crystalline body, obtainable from bile by the action of acids. *Cholesterine* is a crystallizable, fatty constituent of bile, of which it forms only $\frac{1}{10.000}$ part. But it is important as, from its insolubility, when once deposited, it cannot be reabsorbed. Hence, accumulating in the gall bladder, it forms the chief ingredient of *gall stones* or *biliary calculi*. It is a constituent of blood and brains.

**1218. The Pancreatic Fluid** somewhat resembles the saliva.

digestion. 1216. What of the bile? 1217. Of ox bile? Cholesterine? 1218. What

It is alkaline, and rapidly changes starch into sugar; it serves therefore to complete the digestion of amylaceous substances. When agitated with oil, it forms a very perfect emulsion, and undoubtedly promotes the absorption of oily bodies.

**1219.** Besides the bile and pancreatic fluid, the walls of the intestine pour out an *intestinal* juice. By these three alkaline agents the digestion of the mouth is resumed. Starch is rapidly changed to sugar, and sugar to lactic acid. Although the secretions poured into the intestines are all alkaline, yet lactic acid is so rapidly produced that the intestinal mass quickly becomes acidulous. The conditions are thus furnished for the digestion of the nitrogenous substances that are not dissolved in the stomach. The changed food is here termed *chyle.*

**1220. Intestinal Absorption.**—Those substances which are dissolved in water in the intestines are taken up by the veins, while the oily and fatty matters, which are less perfectly dissolved, are absorbed by a special arrangement of vessels called the *lacteals;* these are extremely fine tubes, arising in the intestinal coats. The liquid which enters the lacteals is white, milk-like, and rich in oil. These vessels are gathered into knots or *glands*, so as to be greatly prolonged without consuming space. They finally gather into a tube called the *thoracic duct*, and pour their contents into a large vein near the left shoulder, and thus into the general circulation.

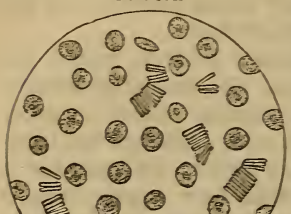
**1221. The Blood.**—The series of changes just described has for its object the preparation from the food of a nutritious fluid to supply materials of renovation and growth to all parts of the body. This fluid is *the blood* and the apparatus of tubes (*blood vessels*) by which it is conveyed, is termed the circulatory system.

**1222.** In man and the higher animals, the blood is red, being of a bright scarlet when taken from the arteries, but of a deep purplish hue when drawn from the veins. It is unctuous to the touch, has a slightly resinous odor, a saline taste, and an alkaline reaction. When first removed from the body, the blood appears to the naked eye a uniform red liquid; but when examined by the microscope it is seen to consist of two distinct parts—a clear and nearly colorless fluid called the *plasma*, and an immense number

is the pancreatic fluid? 1219. Explain the completion of digestion. 1220 How is intestinal absorption effected? What of the lacteals, glands, &c.? 1221. State the object of all these changes? What is the circulatory system? 1222. Describe the

of minute, rounded red particles floating in this liquid, which are known as *blood globules*, or *blood corpuscles*. These vary greatly in size and form in different animals. In man they are flat discs, which have a diameter of about the $\frac{1}{3200}$ of an inch, and are one fourth as thick. The corpuscles consist of a thick albuminous membrane called *globulin*, filled with a red coloring matter, termed *hematin*, in which iron is a large element.

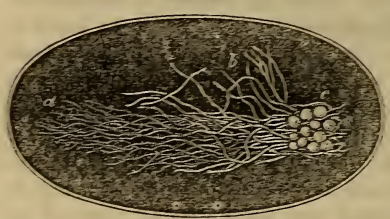
Fig. 304.



Microscopical Appearance of Blood Discs.

**1223. Coagulation.** After the blood has been removed from the body for a short time, it spontaneously coagulates, separating into a dark red jelly, or clot (*crassamentum*), and a pale colored slimy liquid (*serum*). Coagulation is caused by the change of soluble fibrin contained in blood to the insoluble state. The clot consists of fine fibrous threads, enclosing the red corpuscles, Fig. 305. It was formerly supposed to be owing to the death of the blood, but the same effect is constantly taking place within the body, as the liquid fibrin of the blood is deposited to produce solid flesh. As the fibrin coagulates it forms a fine network or jelly throughout the liquid, which entangles and encloses the red corpuscles. It also contains a portion of the serum, which may be removed by pressure. The serum consists of water, albumen, fatty matter, and various salts.

Fig. 305.




*a b*, fibres formed in coagulated blood; *c*, discs entrapped in the meshes. (Magnified 280 times.)

**1224. Composition.**—This varies with age, sex, and the state of the individual. The chief constituents of the blood of man, according to Becquerel and Rodier, are as follows:

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blood. Of what does it consist? What of the corpuscles? 1223. What is coagulation? How is it caused? 1224. What are the constituents of blood?

| | |
|---|---|
| Water, | 779.00 |
| Fibrin, | 2.20 |
| Fatty Matters, | 1.60 |
| Albumen, | 69.40 |
| Blood Corpuscles, | 141.10 |
| Extractive Matters, | 6.80 |
| | 1000.10 |
| Salts, | 6.50 |

# CHAPTER XXIX.

## FINAL DESTINATION OF FOOD.

### § I. *Animal Nutrition.*

**1225.** In the present chapter we consider the final uses of food —the sequel of the course of chemical changes unfolded in the preceding pages. Plant products were divided at the outset into two groups, the nitrogenous and the non-nitrogenous. We next found a twofold digestion conforming to this distinction, and we are now to find that this fundamental difference is observed in their ultimate uses. The nitrogenous class serves the purposes of *nutrition*, the formation of structure; the non-nitrogenous serve the purposes of *respiration*, and are chiefly devoted to the production of animal heat.

**1226. The Living Body a Furnace.**—The living body is a regulated furnace. Its constituents are combustible: a vital fire is sustained in the organism from birth to death, and the inhalation of oxygen is the draught by which it is supported. But this combustion must take place in such a manner that other important objects can be accomplished; while heat is to be constantly maintained in 'the house we live in,' the structure must not be burned down in the process.

**1227.** Nitrogen is incombustible, and lowers the combustibility of all compounds into which it enters. Even hydrogen and phosphorus lose their combustibility by union with nitrogen. The nitrogen of albuminous compounds, which gives them a low combustibility, adapts them to form the bodily structures which are to

1225. What are we now to consider? What of the distinction between the nitrogenous and non-nitrogenous bodies? 1226. How is the living body a furnace? What precaution is necessary? 1227. How does nitrogen influence com-

have a certain degree of permanence. What the iron is to the stove, the nitrogenous tissues are to the living body; they enclose and retain the non-nitrogenous as fuel. Both the fuel and the structure are essentially combustible; the stove 'burns out' in time, and the bodily tissues waste continually; but the difference between the two is sufficient for the great purposes of the animal economy. LIEBIG remarks: 'Without the powerful resistance which the nitrogenous constituents of the body oppose, beyond all other parts, to the action of the air, life could not subsist.'

**1228. Office of Albumen.**—When it was discovered that albuminous substances are isomeric and convertible, and that they originate in the vegetable kingdom, the problem of animal nutrition was at once and greatly simplified. Albumen was found to be the universal starting point of animal nutrition—the liquid basis of tissue and bodily development. This is strikingly illustrated by the process which takes place in the bird's egg during incubation. Under the influence of warmth, and by the action of oxygen, which enters through the porous shell—the same conditions as those which accompany respiration—all the tissues, membranes, and bones (by the aid of lime from the shell) are developed. The foundation material from which they are all derived is albumen, and from this also originate the growth and constant reproduction of our own bodies during life.

**1229. Nutrition of the Tissues.**—The nutrition of the animal structures is, therefore, in a chemical point of view, a very simple process; albumen is changed into fibrin, and fibrin to tissue. Albumen coagulates into a brittle mass, but fibrin, as we have seen, coagulates into tough, thread-like fibres, so that blood in which it is dissolved has been very properly called 'liquid flesh.' The relations of albumen, fibrin, and flesh have been aptly compared to those of raw cotton, the spun yarn, and the woven fabric. The conversion of albumen into fibrin, which commences in the lacteals and continues in the blood, is therefore a simple flesh-forming process. The product necessarily remains in a liquid state, that it may be distributed by the circulation into all parts of the system, while it gradually coagulates into muscular tissue. Cell growth is the instrumentality of change.

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bustibility? State the comparison. What is LIEBIG'S remark? 1228. What is the office of albumen? Give the illustration. 1229. Define the nutrition of animal tissues. What comparison is used? What of the fibrin formed,

**1230. Limit to the Nutritive Power.**—There is no evidence that the living system has the power of converting one element into another. It may transmute compounds of similar constitution one into another, and it can destroy substances by a progressive series of changes, giving rise to new products at each descending step. But it can neither work *upward*, like the plant, nor combine for its own use materials that are present. The dissevered constituents of used-up tissues exist in the blood, but it is entirely incapable of reconverting them into tissue. Nor has the body the power of transmuting the non-nitrogenous group into the nutritive, or of enabling the former to replace the latter in the exigences of the animal economy. It cannot make starch do the work of gluten. That nutrition consists essentially in the assimilation of albuminous bodies, is now one of the best established principles of physiology.

**1231.** Yet the respiratory substances, though incapable of forming tissue, may yet essentially aid nutrition: such is the case with the fats. If the conversion of albumen into fibrin is incomplete, the tissues are imperfectly nourished. The formation of tubercles in the lungs, which gives rise to 'consumption,' is due to this cause, as tubercular matter consists of half-formed cells and coagulated albumen deposited in the pulmonary tissue. The cause of this abortive nutrition is not the lack of sufficient nitrogenous matter to nourish tissue, but of some other principle. It has been recently maintained that it is due to a deficiency of the oily matter which is necessary for the formation of cells, and the growth of healthy structure. Cod liver oil and a free use of the fatty kinds of diet are recommended for such cases.

**1232. Nitrogenous Diet.**—None of the alimentary principles taken alone will support life; a mixed diet is therefore required. But the proportion of the ingredients varies in different circumstances. Severe exercise rapidly consumes the tissues, and necessitates a diet rich in nitrogenous principles. In childhood there is a double demand for these constituents, to supply the constant waste and promote growth. Milk, rich in nutrient matters, is the food furnished them by nature, and when replaced it should only

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and of cell growth? 1230. State the power of the living system. Of what is it incapable? In what does nutrition consist? 1231. What of the respiratory substances? How does consumption illustrate their value? State the remedy proposed. 1232. What is said of the alimentary principles? Of the food of children?

be by a generous, blood-producing diet such as milk, bread, meat, eggs. There is apt to occur in children a deficiency in phosphate of lime from the rapid formation of bone, and as the articles just mentioned contain an excess of phosphoric acid, lime water is often a good addition to their food.

1233. **Respiratory Foods.**—The respiratory principles taken into the system are either burned at once in the blood for the production of heat, or they accumulate as fat. The demand for them varies with temperature, which depends upon season and climate. In summer, or in the tropical regions, where the temperature of the surrounding air rises nearly if not quite to blood heat (98°), there can be but slight necessity for generating heat within. Under those circumstances a diet of vegetables and fruits, with a low proportion of carbon and hydrogen, is selected by instinct. On the other hand, in winter or in the polar regions, where the temperature falls 100° or 150° below that of the body, a rich, heat-producing diet is required, and man instinctively seeks for fatty and oily foods. In northern regions blubber and oil are consumed in vast quantities. The greater density of the air in these cases also increases internal oxidation and the consequent heat.

1234. **Nutritive Value of Food.**—The first step in determining this is to remove the water, which varies in amount from 10 to 98 per cent. in different kinds of food; they are thus reduced to the same condition. Its nutritive value is then determined by a comparison between the quantities of the two classes of ingredients. But the respiratory substances vary in heat-producing effect; 10 parts of fat equalling in this respect 24 of starch. By multiplying the fat by 2.4 it is reduced to its equivalent in starch. Thus the 9 per cent. of oil in Indian corn is equal to adding 22 per cent. to its real amount of starch. On the contrary, albuminous substances, whether in the form of albumen, gluten, or casein, have equal nutritive powers. Hence, by comparing the nitrogenous constituents of food with the respiratory, reduced to the expression for starch, we can determine the adaptation of any article of diet to the two great functions of the living system. The following table from LIEBIG presents the comparison:

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1233. Of the respiratory foods? How does instinct lead us to select food? 1234. How is the nutritive value of foods determined? How is milk adapted to the

| | | *Nutritive.* | *Respiratory.* |
|---|---|---|---|
| Cow's milk | contains, for | 10 | 30 |
| Human milk | " | 10 | 40 |
| Horse beans | " | 10 | 22 |
| Peas | " | 10 | 23 |
| Fat mutton | " | 10 | 27 |
| Fat pork | " | 10 | 30 |
| Beef | " | 10 | 17 |
| Veal | " | 10 | 1 |
| Wheat flour | " | 10 | 46 |
| Oat meal | " | 10 | 50 |
| Rye flour | " | 10 | 57 |
| Barley | " | 10 | 57 |
| Potatoes (white) | " | 10 | 86 |
| Potatoes (blue) | " | 10 | 115 |
| Rice | " | 10 | 123 |
| Buckwheat | " | 10 | 130 |

The above can be regarded only as an average and approximate statement. There is much variation in the proportions of the same class of substances, as we see in potatoes, and it must be still greater in different samples of the same kind of meat; nor can any such statement be relied upon as of itself a sufficient guide in the matter of diet. Still it is useful and rich in suggestions. Milk, for example, is the diet of a *growing* animal. It must furnish nitrogenous material both for current waste and for increased development; hence it abounds in the curdy ingredient. But its properties are admirably modified to suit special circumstances. Of all the young of the animal world, none lead so quiet a life, or advance so slowly to maturity, as the human infant; therefore human milk is less rich in muscle-forming constituents than that of animals—the cow, for example, whose young develop more quickly, and exert themselves much earlier.

**1235. Metamorphosis of Tissue.**—Some substances have the power of influencing tissue changes without properly participating in them. Some increase metamorphosis; others check it. Common salt, for example, and an excess of water, act as hasteners of transformation, while alcohol and tea act as arresters of change. If we consume those substances which augment waste, it is said we require a fuller diet to compensate for the extra loss, or the body declines in weight with more rapidity than otherwise. But if we employ the arresters of metamorphosis, we save tissue,

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young? 1235. How do different substances influence physiological changes? What is the effect of water and salt? Tea and alcohol? 1236. Why does the sys-

and can maintain our usual strength and weight on a more slender diet. The subject requires further elucidation.*

## § II. *Respiration and Circulation.*

**1236. Destructive Force in the System.**—Reparation of the body implies its waste; nutrition presupposes destruction. Aliment is constantly supplied to the system, because it is constantly consumed. The tissue is the seat of a kind of *polarity*; waste and supply in the healthy adult are equal and opposite forces.

**1237.**—As the body does not increase in weight, though matter is constantly added to it, the destructive process going on within must be sufficiently active to use up and carry away the same amount of matter that is supplied through the channels of nutrition. The source of this perpetual waste and destruction is the act of *respiration*, by which air is brought into contact with every portion of the animal fabric.

**1233. Nature of Respiration.**—The relation of animals to the atmosphere is of the most direct and vital nature. All the peculiar processes which take place in the animal structure and which we call *life*, are set in motion and kept in motion by atmospheric oxygen. Its effect is exerted upon the body through the medium of the *respiratory organs*. The action of oxygen is exactly of the same nature in all animals; but the structure and arrangement of the respiratory mechanism differ according as they are destined to be acted upon by oxygen in the condition of a gas, or in a state of solution in water. Animals inhabiting the water have their breathing organs outside the body; in air-breathing animals they are within. In marine animals they are termed *bronchia* or *gills*, and are composed of feathery filaments, or tufts of blood vessels, situated externally, so as to be acted on by air contained in the water. The higher animals respire by lungs, which consist of membranous bags lodged within the body. They contain millions of air cells, which are connected with the atmosphere by the

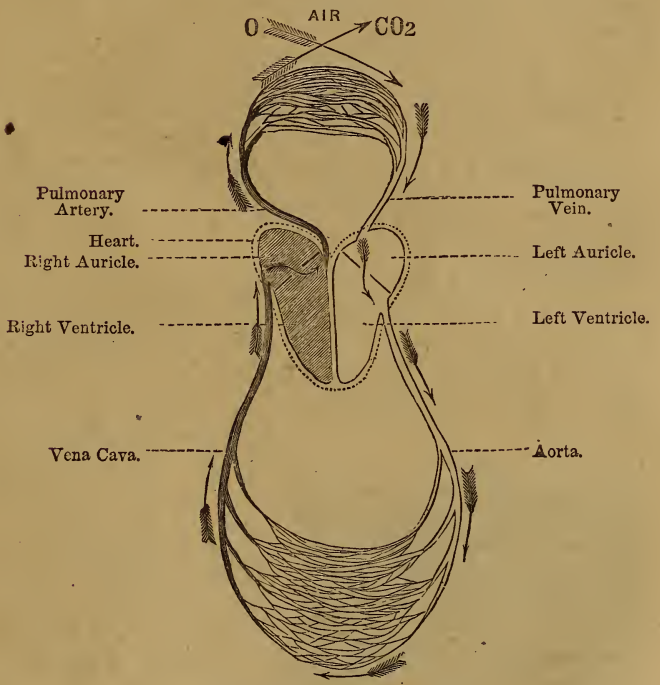
* For a much more extended discussion of the physiological effects of food, the student is referred to the author's "Household Science."

tem require food? What of its forces? 1237. What is the extent of the destructive force? Its source? 1238. What is the relation of oxygen to life? Its medium? How do the respiratory organs differ? Describe the gills. Lungs. 1239. How

trachea and its branchings, and are surrounded by a delicate membrane many times more extended than the surface of the body.

**1239.** The lungs completely fill the cavity of the chest, so that, by the alternate expansion and contraction of the surrounding walls and floor, they are correspondingly enlarged and diminished in size. The contractile pressure of the chest drives the air out (*expiration*), and when the muscles are relaxed, the external pressure of the atmosphere forces it back again (*inspiration*).

FIG. 306.




Ideal view of the Circulation in Man.

**1240. Circulation.**—Air, entering the lungs, fills and distends the numberless little air cells. The enclosing membrane is overspread with the finest network of capillary blood vessels. Pene-

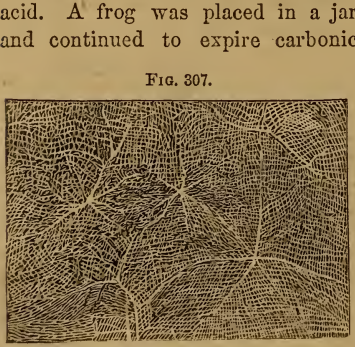
do the lungs act in breathing? 1240. Describe the process of circulation. What

trating the membrane, oxygen enters the blood, and, imparting to it a bright crimson color, rushes forward with it toward the heart. From the heart the blood passes through the arteries to all portions of the body. These arteries divide and subdivide until they are reduced to the finest tubes, which are densely interlaced through all parts of the body. As they are distributed through the system, they are called *systemic capillaries*. In these vessels the oxygen is changed to carbonic acid, and the arterial blood to venous blood. Passing forward, it is gathered into the veins, returned to the heart, and then driven back to the lungs. Here the carbonic acid escapes through the membranes into the air cells; it then diffuses into the bronchial passages and is expelled into the air.

**1241.** Fig. 306 is an ideal representation of the double circulation in man. The fine lines at the top represent the capillaries of the lungs; and at the bottom those of the general system. The double circulation is shown, and its relation to the heart. The vessels on the right side represent the arteries carrying blood charged with oxygen, and those on the left side the veins conveying carbonic acid.

**1242. Oxidation throughout the System.**—It was formerly supposed that oxygen combined with carbon and hydrogen directly in the lungs, but it has been proved that animals respiring pure hydrogen or nitrogen continue for some time to exhale carbonic acid. A frog was placed in a jar of hydrogen over mercury, and continued to expire carbonic acid for eight hours, thus showing that the changes do not take place immediately in the lungs, but throughout the system, and are due to oxygen previously absorbed. The physiological changes proceed so sluggishly in reptiles that they will live long in conditions of the atmosphere which would be quickly fatal to higher animals.

FIG. 307.



Capillary vessels of the Liver.

are the systemic capillaries? What are the further changes? 1241. What does Fig. 306 illustrate? 1242. Where was oxidation formerly supposed to take place? What does the experiment with the frog prove? What of reptiles? 1243. What

**1243.**—In the fine blood vessels distributed throughout the body, oxygen is constantly changed to carbonic acid, and arterial to venous blood. The minuteness of these vessels is surprising. They are termed capillary, or hair-like, but they are far smaller than hairs. Fig. 307 shows the densely crowded blood vessels on the surface of a rabbit's liver, magnified eleven times. Through these wondrously fine tubes flows the vital stream, bringing the materials of nutrition, bearing away the products of waste, and itself incessantly changing as it presses on.

**1244. Conveyance of Oxygen.**—In what manner the blood takes up the oxygen and transports it, is not so clearly seen. The absorbent power of its water is insufficient. LIEBIG's suggestion that the iron of the blood is the carrier, is unsatisfactory. The blood discs are the agents of transportation, and it is probable that they hold the oxygen in a peculiarly loose condition of union, surrendering it at all points to enter into other combinations.

**1245. Gases Absorbed and Exhaled.**—Abut 5 per cent. of the oxygen inhaled is absorbed by the blood. When oxygen combines with carbon, the bulk of the carbonic acid formed is exactly equal to that of the uniting oxygen. If, therefore, all the oxygen taken into the system were converted into carbonic acid, the amount of this gas exhaled would just equal the oxygen inhaled. But this is not the case. The expired breath contains on an average about one seventh less than the absorbed oxygen. This deficiency combines with hydrogen, and appears in the breath as exhaled watery vapor. The bulk of the expired air is greater than that inhaled, owing to the presence of moisture and its high temperature.

**1246.** The average amount of air inspired and exhaled at each respiration is 30 cubic inches, and the average number of respirations 20 per minute, so that 500 cubic feet of air pass through the lungs in 24 hours. The amount of carbonic acid exhaled is variable, and is interesting as the index of the rate of internal change. The more energetic the circulation, the larger the quantity of carbonic acid; it is less during sleep than while awake, and less during fasting than after a full meal.

**1247.** How the expired carbonic acid may be measured is shown

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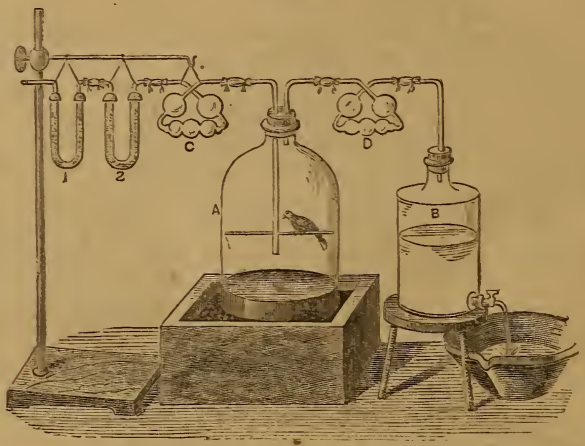
processes go on in the capillaries? How is their minuteness shown? 1244. How is oxygen probably conveyed? 1245. What of the gases absorbed? Of those exhaled? 1246. How much air passes through the lungs in 24 hours? What of the amount of

in Fig. 308. A bird is placed in a bell glass, *A*, which stands over mercury. *B* is a vessel of water which establishes a current of air through the apparatus as its water flows out. The tubes 1 and 2 contain pumice stone moistened with potash, which absorbs all the carbonic acid from the entering air. The bulbs, *C*, contain lime water, and the fact that it remains clear proves that the air enters the bell glass free from carbonic acid. The air which the bird expires

FIG. 308.




Measuring the Carbonic Acid exhaled by a Bird.

is drawn through the bulbs, *D*, containing lime water or potash, which had been carefully weighed. The carbonic acid exhaled by the bird is absorbed, and if the bulbs are again weighed after a given time, they indicate the amount of $CO_2$ exhaled by the bird.

**1248. The Discovery of the Circulation** was made upward of two hundred years ago by Dr. HARVEY, but of its cause he had no true idea. This could not be known until the microscope was perfected, the capillary mechanism explained, and the sciences of chemistry and molecular physics developed. In the absence of real knowledge, the circulation of the blood has been ascribed to the drawing and driving action of the heart.

**1249. Office of the Heart.**—While it is admitted that the im-

carbonic acid exhaled. 1247. How is it measured? 1248. What of Dr. HARVEY in relation to the circulation of the blood? What was necessary to explain its cause? To what has it been ascribed? 1249. To what degree does the heart move the

pelling action of the heart moves the blood through the large tubes, it is equally certain that it cannot drive it through the capillaries: the force which acts *here* is the real cause of the circulation. There are animals destitute of a heart, but still with a definite circulation. Fishes have no heart on the arterial side between the lungs (gills) and the systemic capillaries. The heart is introduced into the mechanism of the higher and rapidly acting animals as a *regulator*, rather than a *motor:* it is the beating pendulum; the falling weight is to be sought in the capillary system.

**1250. Theory of the Circulation.**—Dr. DRAPER has given an explanation of the causes of the circulation of the blood on physical and chemical principles, and brought us nearer to a final solution of this interesting problem than any former investigator. We have seen how fluids rise in tubes by wetting their sides. When two liquids meet in a tube with unequal affinities for its walls, the one having the highest attraction will drive the other before it. The arterial blood is charged with oxygen which has a high affinity for the walls of the capillary tissues. As the oxygen enters into combination with the materials it meets with, its affinity is satisfied, and arterial is changed to venous blood, which is driven forward by the constant pressure of the arterial current behind. The circulation is thus immediately due to respiration. Dr. DRAPER applies the same principle to the flow of sap in plants. Water of the soil, entering the rootlets and rising through the trunk and branches by osmose, passes into the leaf, and is there digested. The new gummy, or colloid product has less affinity for the walls of the tubes and tissue, and is constantly pushed forward by the freshly arriving sap. For illustrations of this view, see DRAPER'S Human Physiology.

**1251. Influence of Air.**—From the foregoing considerations it will be seen that the influence of air is all controlling over the human constitution; it is the first condition of vital activity—the immediate impelling power of life. Any one of its elements breathed alone would be fatal; any other proportions would be dangerous, but mingled as they are, how bland, how balmy, how salutary they become! It presses upon us with the weight of tons; bathes the sensitive passages, distends the filmy mem-

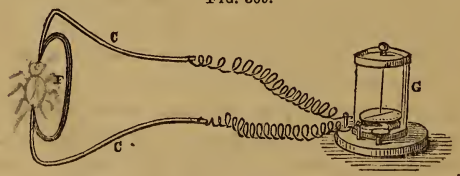
blood? Where is the seat of chief action, and how proved? What is the function of the heart? 1250. What is said of Dr. DRAPER'S theory? Explain it. How is it elsewhere applied? 1251. What is said of the influence of air? 1252. What is stated

branes of the air cells, and flashing through into the blood, is swept forward to the inmost depths of the system, corroding and consuming in its progress the living parts; and yet with such marvellous delicacy are all these things accomplished, that we remain profoundly unconscious of them. Science has shown that there is a deep life-import in these never-ceasing rhythmic movements of inspiration and expiration, but it can add nothing to the simple grandeur of the primeval statement that the Creator 'breathed into his nostrils the breath of life, and man became a living soul.'

## § III. *Production of Animal Heat.*

**1252. All Animals produce Heat.**—If water containing animalcules be gradually frozen under a microscope, the last drops seen to congeal are those which surround their bodies. From this point upward, each class generates an amount of heat peculiar to itself. The temperature of the human body may be ascertained by placing the bulb of a delicate thermometer under the tongue, but to measure more minute quantities of animal heat than this instrument can detect, the thermo-electric couple is employed. The action

Fig. 309.



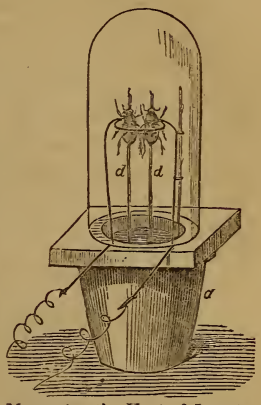

Galvanometer for measuring Animal Heat.

of the latter instrument has already been described. In Fig. 309 *F* represents an iron needle bent at the ends and soldered to *c c*, copper wires which are connected with a galvanometer *G*. As long as both points are at the same temperature the needle remains at rest; but it moves when the heat of one exceeds that of the other. It was desired, for example, to compare the temperature of a living and a dead insect. Each was fixed on a stick *d d*, Fig. 310, planted in the earth of a flower pot *a*. The needles were

of animal heat? How is it measured? 1253. What is said of the heat of the hu-

then thrust into corresponding parts of the living and dead insect, when the motion of the galvanometer indicated the difference of their temperatures.

Fig. 310.




Measuring the Heat of Insects.

**1253. Temperature in Man.**—The heat of the human body varies but slightly from 98° the world over, though the external temperature changes daily and hourly, while the variation from latitudes and seasons is very great. The extremes of equatorial midsummer and arctic midwinter embrace a range of more than 200°, yet through all these thermal vicissitudes the body of a man in health deviates but little from the constant normal of 98°.

**1254.**—In view of these facts it has been maintained that the living body has some vital, mysterious, internal defence against the influence of external agents. But this is erroneous. It is a heated mass which has precisely the same relations to surrounding objects as any other heated mass. When they are hotter than itself, it receives heat; when they are colder, it loses heat, and the rate of heating or cooling depends upon the difference between the temperature of the body and that of its surrounding medium. But in nearly all circumstances the temperature of the body is higher than the objects around it; hence, it is almost constantly losing heat by radiation, conduction, and evaporation.

**1255. Nervous Agency.**—Animal heat has been ascribed to nervous agency, but such an idea is clearly disproved by what takes place in plants. There are two marked periods in the life of a plant in which it exercises the heat-evolving function, and becomes independent of surrounding temperature. This occurs in the germination of seeds and in flowering. A thermometer placed in a bunch of arum flowers rose to 121°, when the temperature of the air was but 60°. As plants have no nervous system, the effect in this case cannot be due to nervous action. The

man body? 1254. How has it been accounted for? What are the facts in the case? 1255. To what else has animal heat been ascribed? What disproves this view? How is it related to the nervous system? 1256. To what is plant heat

production of heat in the animal body is under the control of the nervous system probably in the same way that the fire that drives the steam engine is under the control of the fireman.

**1256. Cause of the Plant Heat.**—In both of the cases referred to there is an absorption of oxygen, which unites with the sugar of the flower and the oil of the seed, and a liberation of carbonic acid in exact proportion. That the heat is due chiefly to oxidation is proved by the fact, that when no oxygen is present, heat is not evolved; whereas, if pure oxygen gas is employed, the liberation of heat is more rapid than usual.

**1257. Cause of Animal Heat.**—The union of oxygen with carbon and hydrogen is a source of heat under varied conditions. We can combine them in no way without producing heat. The animal body inhales oxygen and exhales carbonic acid; there has therefore been a union, and that union must have produced heat. Here is a real cause, and one adequate to account for nineteen twentieths of the heat generated in the body. Muscular and nervous action produce heat, and this may probably explain the source of the deficiency.

**1258. Effect of the Rate of Respiration.**—The amount of heat generated in an animal is strictly connected with its rate of respiration, and the amount of oxygen it absorbs. In reptiles and fishes the structure of the respiratory organs is such that but a small proportion of oxygen is taken into the system. The quantity of heat produced is therefore small. Their temperature rises and falls with that of the surrounding medium, and is never but little above it; hence they are called *cold-blooded* animals. The respiratory mechanism of birds, on the contrary, is on a most perfect plan; it works rapidly, and their temperature is consequently maintained at a high rate, from 100° to 112°. Infants breathe more rapidly than adults, and their temperature is several degrees higher.

**1259. Hibernation.**—The most striking illustration of the influence of respiration over bodily heat is seen in the case of those animals which pass the winter season in a state of profound sleep, or torpor (*hibernation*). In this condition the breathing becomes

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chiefly due? How proved? 1257. How do you account for animal heat? What of muscular and nervous action? 1258. With what is the heat connected? Why are reptiles and fishes 'cold-blooded?' What of birds and infants? 1259. What does hibernation illustrate? Describe the state. Give some facts in regard to hi-

very slow, the imperfectly oxygenated blood flows sluggishly through the heart, and the heat of the animal falls, it may be, almost to the freezing point. The marmot, in summer, is warm-blooded; but as it passes into hibernation, the number of respirations falls from 500 to 14 in an hour, the pulse at the same time sinking from 150 to 15 per minute. An animal in hibernation has been placed in an atmosphere of pure carbonic acid and remained there four hours without injury, while if thus treated in its active condition, it would have perished instantly.

**1260. Spontaneous Combustion.**—There has long prevailed an opinion that the living body, under some circumstances, might take fire and be more or less completely consumed, and many cases of this kind are on record. LIEBIG, however, has demonstrated the impossibility of any such result, and affirms that no amount of fat, alcohol, or phosphorus which the living body could possibly contain, would render it combustible. Upon examination, the alleged instances of spontaneous combustion were found to be in no case entitled to credence.

## § IV. *Production of Animal Power.*

**1261.** The amount of thermal force generated annually in the body of an adult man is sufficient to raise from 25,000 to 30,000 lbs. of water from the freezing to the boiling point. All the acts of the body, every motion, utterance, breath, or thought consumes force. We make about 9,000,000 separate motions of breathing in a year; thereby inhaling and expelling 700,000 gallons of air. At the same time the heart contracts and dilates 40,000,000 times—each time with an estimated force of 13 lbs., while thousands of tons of blood are annually driven through the heart and general system. Besides these involuntary acts, the organism generates force for a thousand forms of voluntary, physical action. A healthy laborer is assumed to be able to exert a force equal to raising the weight of his body through 10,000 feet in a day.

**1262. Rate of Physiological Change.**—Corresponding to this activity is a high rate of internal change. The living body is like

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bernation. 1260. What is said of spontaneous combustion? 1261. How much heat does a man annually produce? How many motions of breathing? What amount of air does he respire? How many motions of the heart does he make? How much force can a laborer exert? 1262. What amount of food does a man con-

a waterfall; while it appears an unvarying form it is yet composed of particles in a state of swift transition. A man consumes in a year 800 lbs. of solid food, the same amount of oxygen, and about 1,500 lbs. of water—or altogether a ton and a half of matter. CHOSSAT ascertained the waste in various animals to be an average of $\frac{1}{24}$ of their weight daily, and SCHMIDT determined it to be, in the case of the human being, $\frac{1}{23}$ of the weight. JOHNSTON says: 'an animal when fasting will lose from $\frac{1}{14}$ to $\frac{1}{12}$ of its whole weight in 24 hours'. The waste proceeds so rapidly that the whole human body is believed to be renewed in an average period of not more than 30 days—the man of eighty years has therefore shifted the substance of his corporeal being nearly a thousand times!

**1263. Force Accompanies Change.**—In the exercise of functional power, parts waste and are ever renewed. In all the deepest recesses of the body, in every elastic muscle and conducting nerve, and even in the thinking brain, myriads of atoms are constantly dying and being replaced. As soon as we begin to live and act, we begin to die. The decomposition is in proportion to the activity. Muscles are rapidly changed, and are always more or less acid from the oxidized products in their substance. It has been fully proved by G. Von LIEBIG that muscles absorb oxygen and exhale carbonic acid as long as their contractility lasts. With the exercise of a muscle, blood is urged toward it; if the current is stopped, it is paralyzed. So also with the nervous system; brain power is dependent upon cerebral transformations. Indeed changes go forward more rapidly in the brain than in any other part, and, while cerebral exercise increases the brainward flow, an arrest of the circulation, but for a moment, as in fainting, produces unconsciousness.

**1264. Force the Result of Change.**—It was formerly held that the body acts by virtue of an inherent 'vital property,' and that the changes which go on within it are *consequences* of its activity. This idea was but natural. As Mr. HINTON suggests, if man had first met with steam engines in nature he would have supposed them endowed with a peculiar 'active property,' which

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sume annually? How much oxygen? Water? In what time does the material of the body change? What is said of a man of eighty? 1263. What is the effect of exercise? What is the rate of decomposition? The condition of muscles? What has LIEBIG proved? What is said of cerebral changes? 1264. What was formerly held concerning the action of the body? How is this illustrated by the

caused their movement, and when afterward the expansion and contraction of the steam was discovered, it would have been looked upon as the *result* of the 'inherent activity,' and not as its cause. It was thus with the animal organism; it was studied backward, and effects taken for causes. But science has shown that molecular changes are the causes, and not the consequences of its activity, and that in this respect the living body is analogous to the steam engine and the galvanic battery. In the steam engine, power results from the oxidation of fuel; in the voltaic battery, from the oxidation of zinc; in the living body, from the oxidation of food and tissue.

**1265.** The barbarian explains mechanism by supposing the machine to be alive. 'It died last night,' exclaimed the Chinaman in triumph, upon selling the first watch he had ever seen. It is only when we begin to discover the beautiful unity of Nature's plan that we reverse the primitive notion, and discover the living system to be a divinely constructed machine, adapted to the universal economy of Nature's forces. It is not strange that men were long in perceiving the mechanical relations of the living system, as it is so unlike all other machines in the conditions of its action. It consumes itself and repairs itself. 'It is as if the wheels of the steam engine were made of coal, revolved by their own combustion', and grew as fast as they were consumed.

**1266. Analogies of the Living Body and the Steam Engine.** —These have been traced, in several interesting particulars, as follows:

| THE STEAM ENGINE IN ACTION TAKES— | THE ANIMAL BODY IN LIFE TAKES— |
|---|---|
| 1. FUEL—Coal and wood—both combustible. | 1. FOOD—Vegetables and flesh—both combustible. |
| 2. WATER (for evaporation). | 2. WATER (for circulation). |
| 3. AIR (for combustion). | 3. AIR (for respiration). |
| AND PRODUCES— | AND PRODUCES— |
| 4. A steady boiling heat of 212° by quick combustion. | 4. A steady animal heat of 98° by slow combustion. |
| 5. Smoke, loaded with carbonic acid and watery vapor. | 5. Expired breath, loaded with carbonic acid and watery vapor. |
| 6. Incombustible ash. | 6. Incombustible animal refuse. |

steam engine? To what is the living body analogous in respect to power? 1265. How does the barbarian explain mechanism? When is the opposite view discovered? Why were not the mechanical relations of the body not earlier perceived? What is the mechanical peculiarity of the body? 1266. Mention some points of

| | |
|---|---|
| 7. Motive force of simple alternate push and pull in the piston, which, acting through wheels, bands and levers, does work of endless variety. | 7. Motive force of simple alternate contraction and relaxation in the muscles which, acting through joints, tendons, and levers, does work of endless variety. |
| 8. A deficiency of fuel, water, or air, first disturbs and then stops the motion. | 8. A deficiency of food, drink, or air, first disturbs and then stops the motion and the life. |

**1267. Source of Animal Power.**—Like all other machines, the living body cannot create power; it can only convert and use the stored force of food. The organic spring that was wound up in the plant is relaxed in the animal system, and gives out its force as animal power. And here, under the most complex conditions, we still trace the operation of the great law, that with definite material changes are associated determinate quantities of force. Moreover, we see how the great dynamic scheme of nature is consummated in animal life. Its apparatus is designed for the expenditure of power. The strong, bony system is framed in parts to admit of free motion; its hundreds of muscles are the instruments of action; its circulatory system is the fountain of force, and its nervous system binds all into a unit for effective effort. The energies of the universe are then gathered and poured through it for the accomplishment of the purposes to which it is destined.

**1268.** We have seen that the vegetable kingdom constitutes a fourth reservoir of stored force in the plan of nature (1176). Professor DANA holds that the animal is the fifth and highest form of 'magazined power.' From the immutable or slowly-changing granite we rise through more and more changeable forms of matter, solid, liquid, gaseous, organic, and reach the summit of the scale in the human brain. Dynamically, the rock and the brain are nature's opposite poles. The brain is formed of the most unstable materials, consisting of four fifths water, through which is diffused the cerebral tissue, with a large proportion of uncoagulated albumen, phosphorized oils, and other changeable substances. So rapid are its transformations, that though but $\frac{1}{36}$ the weight of the body, it receives from $\frac{1}{5}$ to $\frac{1}{10}$ of all the blood driven from the heart, to maintain its normal waste and repair. We are

analogy between the living body and the steam engine. 1267. What is the source of animal power? How is the animal body related to the universe? Explain the action of its parts. 1268. How are animals placed in regard to power? What are the opposite extremes of power? State the composition of the brain. Its weight.

to conceive of the brain, therefore, less as a stable organ than as a torrent of change, mind being linked not properly with matter, but with *matter in motion*, or in the highest physiological condition of power.

## CHAPTER XXX.

### CYCLES OF ORGANIC NATURE.

**1269.** That matter changes its form and is put by nature to a succession of uses has long been vaguely understood. Science has given precision to the idea and unfolded a mighty scheme of circulations and compensations by which the balance and harmony of terrestrial affairs is maintained.

**1270. Circulation of Water.**—The equilibrium of the world of waters is preserved by a vast system of circulations; whenever there is movement in one direction, there is counter movement in the opposite. From the surface of sea and land water is rising incessantly by evaporation into the air, but it all descends in the forms of rain, dew and snow, to be again elevated, and again to descend, perpetually.

**1271.** The rivers which flow into the sea correspond to rivers of vapor in the air moving in opposite directions. The water which is decomposed by the plant, and, ministering to its transmutations, is deposited in its structure or its products, is reproduced by the animal, and by the processes of combustion and decay. Thus the waters are carried round in constant circles of distillation and condensation, of decomposition and recomposition, and through this perpetual doing and undoing, the economy of the world and the order of life are maintained upon the planet.

**1272. Circulation of Carbon.**—In the form of carbonic acid this element is withdrawn from the air by plants, and as they slowly decay or rapidly burn, the carbon is again resolved into carbonic acid and restored to the atmosphere. If the vegetable matter is consumed by animals, a like result takes place through their respiration and decay. The same interchange goes on in the sea, for it *must* take place wherever there is life. There is a

Its blood supply. How associated with mind? 1269. What has science unfolded? 1270. How is water kept in circulation? 1271. Describe its changes. 1272. How

marine vegetation so near the surface of lakes and oceans that it may be acted on by light; it absorbs carbonic acid from the water, decomposes it, and fixes its carbon. Aquatic animals consume it and give back carbonic acid by respiration to the watery medium.

**1273.** The time required for the complete revolution of these chemical wheels varies almost infinitely. We may consume fruit in which the formative processes are actively going on, and its sugar will be exhaled from the lungs as carbonic acid, and again absorbed by the leaves in perhaps an hour's time. On the other hand, the carbon of the coal beds, after slumbering in the earth for ages, is but to-day brought forth to be restored as carbonic acid to the air.

**1274.** Again, many tribes of marine animals form coverings of lime and carbonic acid which, accumulating in the course of time at the bottom of oceans, are converted into beds of shelly limestone. In the warmer parts of the ocean, little insects are also busy absorbing the same constituents from the water and building up coral reefs which are thousands of miles in extent. But is not the carbonic acid absorbed by the ocean, and thus, appropriated by its animals, chained down forever in the forming rocks? So it might well seem did we not know that the eternal law of nature is not fixity, but change. The balance that seems lost is still preserved, for carbonic acid, liberated in the depths of the earth from unknown sources and by processes we can but obscurely trace, is everywhere rising to the surface. By myriads of springs, by volcanoes, both active and extinct, in thousands of caves and hollows, in cellars and wells, and from all the soil over vast tracts of country, carbonic acid, in incredible volumes, is being continually set free and poured into the atmosphere.

**1275.** The marvellous perfection and delicacy of these adjustments become more striking when we consider how small an amount of carbon the air contains (570). Notwithstanding the prodigious quantities that are poured into and withdrawn from the air, this small and precise proportion remains unaltered from age to age. Two hundred million tons of coal are now annually consumed, producing six hundred million tons of carbonic acid. A century ago hardly a fraction of this amount was burned, yet the

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is carbon circulated upon land? Upon the sea? 1273. What of the time required for these changes? 1274. How are beds of shelly limestone and coral reefs formed? In what way is the balance preserved? 1275. What is said of the amount

enormous supply has not sensibly disturbed the proportion of this gas in the atmosphere.

**1276. Circulation of other Elements.**—In the same manner oxygen and nitrogen are in perpetual movement. Oxygen enters the plant in a state of combination; it is set free, is absorbed by the animal, combines with its carbon and hydrogen, is returned to the atmosphere, and reëntering the plant, goes the rounds again and continually. Nitrogen, taken into the plant as ammonia, is converted into gluten, albumen, &c., and then, becoming the food of animals, is wrought into their structure. Decomposed and rejected from the animal system, it is again ready to enter the plant. Thus, the antagonism of offices between plants and animals, which maintains the equilibrium of life, is complete. They may be contrasted in their leading functions as follows:

| THE VEGETABLE | THE ANIMAL |
|---|---|
| Absorbs carbonic acid from the air. | Returns carbonic acid to the air. |
| Supplies oxygen to the atmosphere. | Withdraws oxygen from the atmosphere. |
| Decomposes carbonic acid, water, and ammoniacal salts. | Produces carbonic acid, water, and ammoniacal salts. |
| Produces the organic principles of food. | Consumes the organic principles of food. |
| Endows mineral matter with the properties of life. | Deprives organic matter of the properties of life. |
| Imparts to chemical atoms the property of combustibility. | Deprives chemical atoms of the property of combustibility. |
| Imparts to chemical atoms the power of nourishing the animal. | Imparts to chemical atoms the power of nourishing the vegetable. |
| Converts simple into complex compounds. | Converts complex into simple compounds. |
| Is an apparatus of deoxidation. | Is an apparatus of oxidation. |
| Is a mechanism of construction. | Is a mechanism of reduction. |
| Absorbs heat and electricity. | Produces heat and electricity. |

**1277.** And the ethereal atmosphere, so light, so mobile, so attenuated that it seems almost to connect the worlds of matter and of spirit, is the grand theatre of these mighty reactions. It is at once the fountain of life and the source of death. From its serene and inscrutable depths come the mysterious processions of living beings which crowd the earth, and it is the great sepulchre to which they all return; it has received the disrupted and scattered elements

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of carbon in the air? 1276. Describe the changes of oxygen. Of nitrogen. Mention some of the points of contrast between plants and animals. 1277. What is

of the dead of past generations, and is hourly gathering to itself the living of the present.

**1278. Nature a Strict Economist.**—Thus the beautiful and the unsightly, the noxious and the pure, the great and the small are all mingled together, and the same materials are perpetually going their rounds of service. The air we breathe and the water we drink to-day have been breathed and drunk a thousand times before. 'No material is wasted, no force spent in vain.

**1279.** In nothing is the economy of nature more manifest than in the connection of the animal races. Matter and force are not suffered to run to waste by the death of animals which feed upon plants. There are flesh eaters of all grades, from man to the microscopic infusoria, some of which destroy and eat, while others consume only the decomposing dead. The putrefaction of animal carcasses would be offensive and dangerous, and so numberless insect tribes are provided, the larvæ of which devour the decomposing mass, and are themselves eaten by larger animals. In the aquarium, which is a miniature organic world, plants feed animals and animals feed plants; but there must be flesh eaters, for if an animal is left to decay, the water becomes foul, and life is arrested.

**1280. Death Essential to the Order of Nature.**—Life and death are thus bound up indissolubly in the plan of nature. Each implies the other; they are the opposite and equal arms of the organic balance. The death of living parts begins with life, and is essential to life. 'The creation of a plant was the simultaneous institution of life and death—the establishment of an incoming and outgoing stream to be in constant flow as long as the kingdoms of life should last. Vegetable and animal life and death are but parts of one idea involved in a single primal plan.' (Dana.)

**1281. The Course of Change Irresistible.**—Nor is man able to arrest the onward course of natural changes, nor by any arts can he long withdraw the lifeless forms from the resistless currents of circulation. In petty egotism he wraps the bodies of the dead in resinous swathings, and places them in massive mausoleums, so that for hundreds, perhaps thousands of years, they may be kept from mingling with the restless elements; but Time at

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the theatre of all these changes? 1278. What of nature as an economist? 1279. Explain her economy in regard to animals. Where is it illustrated? 1280. What are the mutual relations of life and death? 1281. What is beyond our power? Ex-

last, in his endless vicissitudes, enters the tomb, and restores the forgotten mould to the moving world from whence it came.

**1282. Matter to be Kept Moving.**—But though man cannot arrest the course of nature, he nevertheless has a control over its changes of the highest importance to himself and to society, and which involves very grave responsibilities. Air and water, the great media of circulation, when they have been used, are designed to pass on; we have no right to them beyond their transient employment. They are ours to-day, but to-morrow they belong to all. If we detain and suffer them to stagnate around us, they become the fruitful instruments of disease and death. The very qualities which make them serviceable render them also dangerous. They dissolve various ingredients, which are essential to life, or may become charged with noxious agents, which are fatal to it. Nature avenges herself by inflicting fearful penalties upon individuals and nations who tamper with and violate her laws. The great epidemics, the consuming fevers, the desolating plagues are divine admonitions to the wise that the ordinances of nature are not to be violated with impunity.

**1283. Conclusion.**—And thus our studies lead us to a new perception of that sublime lesson of science—the *Unity of the Universe.* The revolutions of the celestial orbs are paralleled by the ever-recurring cycles of matter upon earth; while the energies in action obey in both cases the same beneficent but inexorable laws. It is the glory of Astronomy to have shown that the harmony of our planetary system is maintained by the eternal war of hostile forces, which by their mutual counteraction keep the heavenly bodies in their circling paths. Chemistry has shown that this great principle is not limited to the field of celestial mechanism, but that it operates also upon earth, and governs the kingdoms of terrestrial life. Here too there are conflict and counteraction—the omnipresent antagonism of warring forces resulting in the harmony and stability of the living world; another illustration of that unity of design and harmony of action throughout the universe which proclaim the government of One Infinite Mind.

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ample. 1282. How are air and water to be regarded? What results from their detention? Examples. 1283. What great lesson are we taught by Science? What has Astronomy proved? How has Chemistry extended this great principle?

# PRONUNCIATION OF SOME TECHNICAL WORDS AND PROPER NAMES USED IN THIS WORK.

## TECHNICAL WORDS.

Aç'-e-tate.
A-çet'-ic.
A-çe'-tous.
A-con'-i-tine (*-tin*).
Al'-de-hyde (*-hyd*).
Al-lo-trop'-ic.
Al-lot'-ro-pism.
Al-u'-mi-num.
A-mŷl'-ic.
An-æs-thet'-ics.
Ar'-a-bin.
A-ther'-mic.
A-tom'-ic.
Bas-so'-rin.
Bi-nox'-ide (*-id*).
Bo-raç'-ic.
Bro'-mine (*-min*).
Brucia (*Bru'-she-ā*).
Bu-tyr'-ic.
Caf-fē'-ine (*-in*).
Caoutchouc (*Ko-chook'*).
Cap'-il-la-ry, or Ca-pil'-la-ry.
Cap'-ro-ic.
Cholesterine (*Ko-les'-ter-in*).
Chlorine (*Klo'-rin*).
Co'-balt, or Cob'-alt.
Col-loid'.
Chry-oph'-o-rus.
Di-al'-y-sis.
Di-dym'-i-um.
Di-e-thy'-la-mine (*-min*).
Er-e-ma-cau'-sis.
E-lec-trol'-y-sis.
E-thy'-la-mine (*-min*).
Eth'-yle (*-il*).
Flu'-o-rine (*-rin*).
Glu-çi'-num.
Guaiacum (*Gwe-ak'-um*).
Glyç'-er-in.
Hel-i-och'-ro-my.
Hip-pu'-ric.
I'-o-dine (*-din*).
In-ter'-sti-ces.
I-som'-er-ism.
I-so-mor'-phism.
Lan'-tha-mum.
Lith'-arge.
Lith'-i-um.
Mate (*Mah'-tā*).
Mer-cap'-tan.
Mor'-phine (*-phin*).
Mol'-e-cule.
Mo-lyb-de'-num.
Nic'-o-tine (*-tin*).
Ni-trog'-e-nous.
O-lef'-i-ant.
Par'-af-fin.
Phe'-nyl.

Pho-çen'-ic.
Pi'-nic.
Pip'-er ine (*-in*).
Plat'-i-num.
Pro'-te-in.
Ptyalin (*Ty'-a-lin*).
Pÿr'-o-gal'-lic.
Pÿr'-o-gens.
Py-ri'-tes.
Quinine (*Kwe-nīne'*, or *Kwin'-in*).
Saccharine (*Sak'-a-rin*).
Sa-li'-va.
Sel'-e-nite.
Se-le'-ni-um.
Sta-lac'-tite.
Sta-lag'-mite.
Strychnine (*Strik'-nin*).
Sul'-phur-ic, or Sul-phu'-ric.
Tar-tar'-ic.
Tet'-a-nus.
The'-ine (*-in*).
Tho-ri'-num.
Tourmaline (*Toor'-ma-lin*).
Tri-e-thy'-la-mine (*-min*).
Vi-tel'-lin.

## PROPER NAMES.

Ampère (*Ang-pāre'*).
Bal-lard'.
Bec'cher.
Berthelot (*Ber-tel-lo'*).
Bologna (*Bo-lon'-yah*).
Boucherie (*Boosh-e-ree'*).
Bournon (*Boor-nong'*).
Boussingault (*Boos'-ang-go*).
Breguet (*Breg-wā'*).
Bunsen (*Boon'-sen*).
Chevreul (*Shev-reul'*).
Chossat (*Shos-sah'*).
Courtois (*Koor-twâ'*).
Descartes (*Day-kart'*).
Dalton (*Dawl'-ton*).
Dobereiner (*Doe-burr'-ein-air*).
Dubois-Reymond (*Du-bwâ-Ray-mond'*).
Dumas (*Du-mah'*).
Dutrochet (*Du-tro-shā'*).
Ehrenberg (*A'-ren-berg*).
Fraunhofer (*Frown'-ho-fer*).
Galvani (*Gal-vah'-nee*).
Gerhardt (*Gair'-hart*).
Gay-Lussac (*Gay-Loos-sac'*).
Grandeau (*Gran-do'*).
Hauy (*A'-wee*).
Humboldt (*Hoom'-bolt*).
Jacobi (*Ya-co'-bee*).
Joule (*Jōle*).
Kirchhoff (*Keer'-shoff*).
Laurent (*Lo'-ront*).
Lavoisier (*Lah-vwâ-ze-ā'*).
Leverrier (*Le-ver-re-ā'*).
Leyden (*Li'-den*).
Liebig (*Lee'-big*).
Matteuci (*Mat-tu'-chee*).
Melloni (*Mel-lo'-nee*).
Mayer (*My'-er*).
Mongolfier (*Mon-gol-fe-ā'*).
Mulder (*Mool'-der*).
Natterer (*Nat'-tāre-ur*).
Niepce (*Ni-eps'*).
Oersted (*Urs'-ted*).
Reaumer (*Ro'-mer*).
Regnault (*Ray-no'*).
Ruhmkorff (*Roohm'-korf*).
Scheele, or Sha'-la.
Schönbein (*Schën'-bine*).
Seguin (*Sa'-gan*).
Sulzer (*Sool'-tser*).

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